AN ADVANCED PRACTICAL PHYSICAL GEOGRAPHY

CAPT. FREDERICK MORROW
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AND
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FOR

PUBLIC AND SECONDARY SCHOOLS

BY

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*WITH ONE HUNDRED AND SIXTY-TWO DIAGRAMS
AND OVER FIVE HUNDRED EXERCISES*

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PREFACE

In writing this book it has been the aim of the authors to present a clear and logical account of geographical phenomena. To do this it has been found necessary to touch lightly some of the main principles of other sciences, such as astronomy, mathematics, geology, and biology. Moreover, in order to comply with and help forward the growing tendency to consider geography as the science which above all others is full of every phase of human interest, the authors have made a definite attempt to show the relation that exists between man and the chief phenomena of nature. Not the least factor in this attempt is the choice of experiments and practical exercises, which are for the most part based upon common experience. At the same time the authors have been careful not to include any such exercises as would be unsuitable or inconvenient in schools. It is intended that the book shall be a standard text-book for students in training-colleges; for those in the middle and higher forms in secondary schools, and more especially for pupils taking the Advanced Course—recognized by the Board of Education—in Geography.

The suggestions of the Board of Education on the teaching of geography, the syllabuses of the Oxford and Cambridge Local examiners, and those of many other public examining bodies have been constantly before the minds of the authors during the compilation of this work. It is therefore with considerable confidence that the book is recommended as containing all that is essential for such examinations as—Cambridge Junior and Senior Locals; Oxford Junior and Senior Locals; Oxford and Cambridge Joint Board, Higher and Lower Certificates; Central Welsh Board Junior and Senior Certificates; Higher and Intermediate Examinations of the Scottish Education Department; Irish Junior, Intermediate, and Senior Grade Examinations; L.C.C. Clerkships; Civil Service Clerkships; London Matriculation; Northern Universities' Matriculation; Army and Navy Entrance; National Froebel Union; the various examinations of the College of Preceptors, etc.

At the close of each chapter are numerous questions selected from recent examination papers. Candidates preparing for examinations will do well to work carefully through these.

The whole range of physical geography is dealt with in five parts: i. Introduction; ii. the Atmosphere; iii. the Hydrosphere; iv. the Lithosphere; v. Maps and Map-making. Each part is complete in itself. Great care has been taken to secure an orderly and lucid treatment of the subjects throughout the book, and due prominence is everywhere given to the relation of cause to effect. If, in some parts, it may be thought that the book assumes too much knowledge on the part of the average student, it must be remembered that the authors take it for granted that the reader is already acquainted with their text-book on *Practical and Experimental Geography.*

Numerous maps and diagrams have been included to illustrate the text, where it was considered that their introduction would assist the student to grasp the subject more readily; but these diagrams are *not* intended to enable the student to dispense with his atlas. The authors would emphasize the fact that the profitable and successful study of geography involves the conjoint use of the atlas and text-book, that no good work can be done if the text-book is used without the atlas, and that no text-book illustrations can compensate for the neglect of a good atlas.

Mr. Lambert desires to record his gratitude to the Rev. T. Gough, B.Sc., the Headmaster of the Retford Grammar School, for his many useful suggestions during the preparation of the book, for the unlimited use of his valuable geographical library, and for his help in correcting the proofs; to Mr. G. R. Davies, B.Sc., and to Mr. F. H. Butler, M.A., for so kindly reading portions of the MS. and making noteworthy additions. Capt. Morrow desires to express his thanks to the Rev. S. Sircom, of St. Xavier's College, Liverpool; and to the Rev. W. Mayo, of Beaumont College, for the able assistance they have given in revising the proof-sheets. And both authors wish to thank Mr. M. J. C. Meiklejohn for his untiring and unstinted guidance of the general design, accuracy, and interest of the work.

Frederick Morrow.
Ernest Lambert.

January 1920.

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CONTENTS

PART I

INTRODUCTION

CHAPTER I

PAGE
Definition and Scope of Physical Geography . 1

CHAPTER II

Properties of Matter 4

CHAPTER III

Heat and Light 16

CHAPTER IV

Reflection and Refraction of Light . . 28

CHAPTER V

Electricity and Magnetism 37

CHAPTER VI

PAGE
The Solar System and the Universe . . 49

CHAPTER VII

Rotation, Revolution, and the Seasons . 67

CHAPTER VIII

Latitude 81

CHAPTER IX

Longitude and Time 97

CHAPTER X

Shape and Size of the Earth . . . 110

PART II

THE ATMOSPHERE

CHAPTER XI

Nature and Constitution of the Atmosphere . 122

CHAPTER XII

Temperature and Pressure of Air . . 131

CHAPTER XIII

PAGE
WINDS 146

CHAPTER XIV

THE MOISTURE IN THE ATMOSPHERE . . . 185

CHAPTER XV

CLIMATE 204

CHAPTER XVI

DISTRIBUTION OF RAINFALL 227

PART III

THE HYDROSPHERE

CHAPTER XVII

THE OCEANS 243

CHAPTER XVIII

WAVES AND TIDES 253

CHAPTER XIX

OCEAN CURRENTS 272

CHAPTER XX

PAGE
Sea-depths and Ocean Bed . . . 293

CHAPTER XXI

Salinity and Temperature of the Sea . . 303

CHAPTER XXII

Elevated Sea-beds and Submerged Land . 318

PART IV

THE LITHOSPHERE

CHAPTER XXIII

Land Forms 329

CHAPTER XXIV

The Rocks of the Earth's Crust . . . 345

CHAPTER XXV

Weathering 357

CHAPTER XXVI

PAGE
Volcanoes and Earthquakes 370

CHAPTER XXVII

Springs 393

CHAPTER XXVIII

Rivers and their Work 408

CHAPTER XXIX

Lakes 443

CHAPTER XXX

Coral Islands 456

CHAPTER XXXI

Glaciers 465

CHAPTER XXXII

Distribution of Plants and Animals . . . 484

CHAPTER XXXIII

Races of Mankind 507

PART V.

MAPS AND MAP-MAKING

CHAPTER XXXIV

PAGE
The Mapping of Areas 528

CHAPTER XXXV

Heights and Distances 544

CHAPTER XXXVI

Contours 554

CHAPTER XXXVII

The Making of Maps 587

LIST AND NUMBERS OF DIAGRAMS

PAGE

1. The Spectrum 21
2. Passage of Light through the Atmosphere . 22
3. Refraction of the Sun's Light 30
4. The Critical Angle at which Refraction changes to Reflection 31
5. Diagram illustrating Length of Day . . 33
6. The Compass Needle 42
7. Diagram illustrating the Solar System . . 49
8. Diagram illustrating the Movements of the Heavenly Bodies 50
9. Diagram illustrating Bodies moving in Different Planes 55
10. Phases of the Moon 57
11. Inclination of Plane of Moon's Orbit to Plane of Earth's Orbit 58
12. Diagram explaining Lunar Eclipses . . 59
13. Diagram explaining the Degree of a Lunar Eclipse 60
14. Breadth of the Lunar Umbra 60
15. An Annular Eclipse 61
16. A Partial Eclipse 61
17. Diagram illustrating the Nebular Hypothesis 63
18. Diagram illustrating the Apparent Movement of the Sun through the Signs of the Zodiac . 70

PAGE
19. Diagram explaining Parallax 72
20. Diagram showing that Parallax is a Proof of Revolution 74
21. Experiment illustrating the Cause of the Seasons 75
22. Illustration of the Varying Incidence of the Sun's Rays 75
23. A Sextant 81
24. Diagram illustrating the Principle of the Construction of a Sextant 82
25. Diagram of the Earth showing Zenith, Nadir, etc. 85
26. Diagram explaining the Determination of Latitude at the Equinoxes 86
27. Method of using an Artificial Horizon . . 88
28. Diagram explaining the Determination of Latitude in Summer 89
29. Diagram explaining the Determination of Latitude in Winter 90
30. Diagram explaining the Determination of Latitude by the Pole Star 92
31. Diagram explaining the Determination of Latitude by any Star 93
32. A Theodolite 98
33. Illustration of the Cosine Rule for determining Distance 101
34. Illustration of the Mid-Latitude Rule for determining Distance 103
35. Illustration of Method employed to determine Equatorial Circumference 112
36. Experiment of Eratosthenes 114
37. Apparatus of Eratosthenes 115
38. Dip of the Visible Horizon 119

PAGE
39. CONVERSION OF TEMPERATURE SCALES . . 135
40. A BAROMETER 139
41. A BAROMETRIC GRADIENT *or* BAROMETRIC CHART OF BRITISH ISLES 147
42. DIAGRAM EXPLAINING DEFLECTION OF WIND IN ACCORDANCE WITH FERREL'S LAW . . . 150
43. DIAGRAM EXPLAINING DEFLECTION OF WIND IN ACCORDANCE WITH FERREL'S LAW AND THAT OF BUYS BALLOT 151
44. LAND AND SEA BREEZES 153
45 and 45A. DIAGRAMS SHOWING PRESSURES OVER ASIATIC CONTINENT DURING SOUTH-WEST AND NORTH-EAST MONSOONS 155, 157
46. DIAGRAM ILLUSTRATING WIND CURRENTS . . 158
47. THEORETICAL DIAGRAM OF WINDS SHOWING DEFLECTION DUE TO EARTH'S ROTATION . . 159
48. HORIZONTAL PRESSURES 162
49. DIAGRAM ILLUSTRATING THE FORMATION OF A CYCLONE 163
50. DIAGRAM OF A CYCLONE 164
51. DIAGRAM OF AN ANTI-CYCLONE 165
52. DIAGRAM OF THE WEDGE 166
53. DIAGRAM OF A SECONDARY CYCLONE . . . 167
54. WEATHER MAP FROM DAILY PAPER . . . 168
55. MAP ILLUSTRATING A SAND-DUNE COAST . . 178
56. MOVING SAND-DUNES 179
57. A WET AND DRY BULB THERMOMETER . . 186
58. EXPERIMENT EXPLAINING THE FORMATION OF DEW 189
59. DIAGRAM EXPLAINING THE FORMATION OF THE STRATUS CLOUD 193
60. DIAGRAM EXPLAINING THE FORMATION OF THE "MACKEREL SKY" 194

PAGE
61. DIAGRAM EXPLAINING THE FORMATION OF THE CUMULUS CLOUD 195
62. CLIMATIC ZONES IN THE ALPS 209
63. THEORETICAL ISOTHERMS OF THE WORLD . . . 219
64. MAP SHOWING JANUARY ISOTHERMS OF THE BRITISH ISLES 220
65. MAP SHOWING JULY ISOTHERMS OF THE BRITISH ISLES 221
66. MAP OF THE LAND HEMISPHERE 245
67. DIAGRAM ILLUSTRATING THE TIDAL RANGE . . 256
68. DIAGRAM ILLUSTRATING THE TIDAL RANGE ON A ROCKY COAST 257
69. DIAGRAM ILLUSTRATING SPRING AND NEAP TIDES . 259
70. CO-TIDAL MAP OF THE BRITISH ISLES 264
71. EXPERIMENT ILLUSTRATING FLOW OF CURRENTS IN THE ATLANTIC 273
72. MAP OF CURRENTS OF THE ATLANTIC OCEAN . . 279
73. MAP OF CURRENTS OF INDIAN OCEAN DURING SUMMER 284
74. MAP OF CURRENTS OF INDIAN OCEAN DURING WINTER 285
75. MAP OF WORLD SHOWING DEPTHS OF OCEAN . . 295
76. DIAGRAM SHOWING TERRIGENOUS AND PELAGIC DEPOSITS 300
77. DIAGRAM OF A LAKE SHOWING TEMPERATURES AT DIFFERENT DEPTHS 309
78. DIAGRAM OF A LAKE SHOWING CHANGES OF TEMPERATURE DUE TO WIND ACTION 310
79. GRAPH SHOWING VERTICAL DISTRIBUTION OF TEMPERATURE IN THE SOUTH ATLANTIC OCEAN 313
80. EXPERIMENT ILLUSTRATING TEMPERATURE IN ENCLOSED SEAS 314

PAGE
81. Diagram explaining Differences in Temperature of the Atlantic Ocean and the Mediterranean Sea 315
82. Diagram explaining Differences in Temperature of the Indian Ocean and the Red Sea . 316
83. Diagrammatic Section of the Weald . . 331
84. Experiment illustrating the Formation of Folded Mountains 333
85. Serrated Type of Coast 341
86 and 87. The Concave Type of Coast . . . 342
88. The Convex Type of Coast 343
89. Sketch-map illustrating the Effect of Currents on Coast-line 343
90. Diagram illustrating the Theoretical Relation of Igneous and Sedimentary Rocks . 348
91. Diagram illustrating Dip, Outcrop, and Strike 350
92. Section of a Volcanic Cone with Details of Cone Structure 377
93. Bunsen's Experiment illustrating Geyser Action 385
94. The Water Table 396
95. The Water Table and Permanent Springs . 397
96. A Permanent and an Intermittent Spring . 398
97. Diagram showing Permanent Saturation of Rock but no Spring 398
98. Diagram showing an Intermittent Spring . 399
99. Diagram of an Artesian Well . . . 401
100. Diagram showing how a River deepens and cuts back its Bed 412
101. Diagram showing the Effect of Alternate Beds of Hard and Soft Rock upon a River's Course 413
102. Diagram showing a Later Stage than in Fig. 101, with Escarpment Formation . 413

PAGE

103 Diagram illustrating the Formation of Waterfalls 414

104. Diagram showing the Flood-Plain of a River and Levées 417

105. Formation of River-terraces 417

106. Diagram illustrating Riverine Erosion of Concave and Convex Banks 423

107. An Oxbow 424

108. Diagram illustrating Early Form of River-development 427

109. Illustration of Simple River-development . 428

110. Diagram illustrating River-capture . . 428

111. Rivers of Northumberland and River-capture 429

112. Experiment illustrating the Relation between the Velocity of a River and the Sediment carried down by it . . . 440

113A and B. Experiment showing the Velocity of a River at Various Depths . . . 441

114. Diagram illustrating Darwin's Coral-island Theory 461

115. Diagram illustrating Murray's Coral-island Theory 462

116. Experiment illustrating Motion of Glaciers . 468

117. Moraines—Lateral and Medial . . . 471

118. The Plane Table 529

119. Plan of Area surveyed with the Plane Table 530

120. Map of School and Surroundings surveyed by the Plane Table 533

121. A Prismatic Compass 534

122. A Survey of a District made with Prismatic Compass 536

123. Diagram explaining the Determination of Azimuth 538

PAGE

124. Diagram illustrating Method of finding the Height of an Inaccessible Object with the Theodolite 545
125. Diagram explaining the Calculation of the Height of a Tower 546
126. Diagram illustrating Method of finding the Height of an Object when the Base-line cannot be drawn towards the Base of the Object 547
127. Measurement of the Distance of an Inaccessible Object 549
128. Diagram illustrating a Second Method for finding the Distance of an Inaccessible Object 549
129. Diagram illustrating a Method for finding the Distance between two Inaccessible Objects 550
130. Contour Map of Conical Peak 556
131. Contour Map of a Saddle-back Pass . . 556
132. A Spur 557
133. A Valley 558
134. A River-gorge 559
135. A Ridge or Plateau 561
136. Contoured Map drawn from a Verbal Description 562
137. Section of a Valley 563
138. A Hachured Map of a Peak 565
139. Oroscopic Map of Isle of Wight . . . 566
140. The Clinometer 569
141. Diagram illustrating the Use of Clinometer in Contour Drawing 572
142. Diagram explaining Horizontal Equivalent and Vertical Interval 573
143. Plotted Contour Map of Part of a Hill . 575

PAGE
144. Diagram illustrating the Plotting of Slopes 579
145. A Contour Map 584
146. A Contour Map 586
147. Projection of Lines drawn on a Globe . 589
148. Illustration of Stereographic Projection . 591
149a. and b. Experiment illustrating Orthographic Projection 592
150. Illustration of a Method for Mapping a Country on Orthographic Projection . . . 593
151. Illustration of Globular or Equidistant Projection 595
152. Illustration of Cylindrical Projection . 596
153. Diagram illustrating a Practical Exercise on Cylindrical Projection 598
154a. and b. Experiment illustrating Mercator's Projection 599
155. Illustration of the Measurement of the Shortest Distance between Two Points on a Sphere (on Mercator's Projection). . 600
156. Diagram illustrating the Advantages of Mercator's Projection to Navigators . . 601
157. Illustration of Conical Projection . . 602
158. Network drawn on Conical Projection . 603
159. Diagram illustrating Modified Conical Projection 603
160a. and b. Diagrams illustrating the Practical Application of the Principle of Conical Projection 604
161. Illustration of Equal-area Cylindrical Projection 606
162. Illustration of Mollweide's Equal-area Projection 607

An Advanced Practical Physical Geography

PART I

INTRODUCTION

CHAPTER I

Definition and Scope of Physical Geography

Definition.—Physical Geography is the science of cause and effect applied to the phenomena of nature. By "nature" is meant the whole universe so far as we know it; by "phenomena" are meant appearances and occurrences, especially those that are scientifically observed. The early name of the science was "Earth-knowledge," a name that was intended to connote general views of all visible created things, including their constitution and properties. Later the science was called "Physiography," and it was intended to cover the general knowledge of the earth, what is on it, in it, and about it in space. As physiography, however, the subject was looked upon as more or less separate from geography *per se*; and not until it was realised that the so-called physiography was the essential foundation for political world-geography was it incorporated with and made a subdivision of that subject.

Physical Geography is so wide in its scope that it requires a working knowledge of many other branches of science. The student of physical geography makes use of the theories and conclusions of specialists in physics, chemistry, geology, astronomy, mathematics, and even biology. From astronomy the student obtains knowledge of the earth as a member of the solar system; from physics he obtains knowledge of light, heat, magnetism, electricity, and mechanics, and their application to the earth and its functions; from chemistry, knowledge of the composition of the substances forming air, water, and the earth's crust, and their mutual interaction; from geology, knowledge of the history and arrangement of the rocks of the crust; from mathematics, knowledge of how to calculate heights and distances, and how to construct maps; and from biology, knowledge of animal and plant life and work.

Cause and Effect.—It is a quite natural tendency for us to seek after the causes of things. By "cause" we mean the circumstance which precedes an effect, and without which that effect would not occur. If an earthquake happened and our houses were shaken, we should say that the earthquake was the *cause* of the houses shaking, and the shaking of the houses we should call the *effect* of such cause. So, again, if a man falls into a river and is drowned, we might say that the cause of his death was his inability to swim. When we have discovered the cause of any phenomenon, we consider we have explained that phenomenon. Scientists take it for granted that every phenomenon has a cause, and that the same cause always produces the same effect; although the same effect is not always due to the same cause. The explanation or statement of the cause of an effect in nature is called a **law of nature.**

Laws of Nature.—A law of nature is simply the expression of a *uniformity* in nature. It is a law of nature that every material thing on the earth tends to fall towards the earth's centre. This law is merely the statement of the effect uniformly produced by the earth upon all bodies on its surface. If there were no uniformity in nature, there would be no laws of nature. The astronomer can foretell the exact time of an eclipse only on the assumption that the course of nature will remain uniform. But, relying upon the assumption that any natural cause produces the same effect to-day as it did a thousand years ago, or as it will produce a thousand years hence, the scientist, by careful observation, experiment, and reasoning, can formulate an accurate and systematic knowledge of the laws of nature.

CHAPTER II

Properties of Matter

Matter.—All knowledge of the world around us comes to us through our senses. And anything which can affect any of our senses, which has weight, and occupies space, we call *matter*. Light and sound affect our senses, but they are not matter. The ground, soil, or rock on which we walk, the water we drink, and the air we breathe, since they have weight and occupy space, are all forms of matter. To a person who had lost the power of using his senses, who could neither see, feel, hear, taste, nor smell, matter would not exist. If, moreover, the qualities of solidity, sweetness, and whiteness could be taken away from a lump of sugar, it is difficult to say what would be left. To discover what matter is from this point of view is, however, the province of Metaphysics, not of Physics. The most that the student of physical science needs to know is that matter is that which gives rise to the phenomena in nature which are perceived by our senses. The words *thing*, *object*, *body*, *substance*, are sometimes used instead of the word matter.

General Properties.—Every material object possesses certain qualities or properties which we get to know of through one or more of our senses—aided sometimes by instruments. A piece of wood, for example, has its special colour; it has size, weight, and hardness; and it will burn. Hence we say that its properties are redness, hardness, combustibility, etc. Or again, a piece of sponge has the properties of porosity, softness, compressibility, etc. Certain *general* properties belong to all kinds of matter; other properties, called *specific* or *particular*, belong only to some kinds of matter. Thus sweetness is a specific property of sugar, but not of paraffin oil, though both have the general property of weight. The general properties of matter are: Extension, Impenetrability, Inertia, Porosity, Compressibility, Elasticity, Divisibility, Indestructibility, and Weight.

Extension and Impenetrability.—Fill a glass with water, and into it drop a large stone. Some of the water overflows from the glass, showing that room had to be made for the stone. Every kind of matter must occupy a certain amount of space or room: that is—every substance has its own length, breadth, and thickness, however small.* That which does not occupy space is not matter. This property of filling a certain amount of space is called **extension.** But because of this property, it easily follows that no two bodies can occupy the same space at the same time. You cannot put a brick into a brick. This second property, which is really only a factor of extension, is sometimes spoken of as a separate property and named **impenetrability.**

Inertia.—If you are riding in a carriage and it suddenly stops, you will be thrown forward, because your body continues its motion after the stopping of the carriage. In the same way, when the carriage suddenly starts, your body is thrown backwards, because it tends to continue in a state of rest. Every particle of matter in the world is either at rest or in motion, and no particle has the power in itself either to move, or to stop, or to change its direction. The property of resistance to change is called **inertia.** Notice, next time you see one, which way a cycle-rider leans when he turns a sharp corner, especially if he is going at a great rate. Then, remembering the property of inertia, explain to yourself the reason. Try also to account for the high banks at the bends of a cycle-racing track.

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* Though we cannot speak of the dimensions of a gas, yet each molecule of a gas necessarily occupies its own tiny amount of space.

Porosity.—In some objects, such as bread, sponge, pumice-stone, cane, etc., the holes or *pores* can be seen. These are called *sensible* pores. In other substances the pores cannot be seen, though they can easily be proved to exist. It is well known that paraffin sweats through the metal vessel of a lamp. Or again, if a piece of chalk be placed in a vessel of water, air-bubbles rise to the surface as the air is driven out of the pores of the chalk by the absorption of the water. The porosity of metal can be proved by a simple experiment with a metal ring through which a steel ball, when cold, will just exactly pass. Heat the ball in an oven, and you will find that it will not then pass through the ring; but when cooled to its original temperature it will again pass through. Therefore, in changing from the heated condition to the cool condition, shrinkage or contraction must have taken place; that is, the molecules have come closer together, which could not happen if there were no pores. These invisible pores, or *interstices*, are called *physical* pores.

Compressibility.—This property follows from that of porosity; for naturally the more porous a body is, the more compressible it must be: or, just as substances vary in porosity, so do they vary in compressibility. When you squeeze the water out of your sponge you have an excellent example of the great compressibility of a very porous substance. Gases, because their molecules are at a considerable distance from one another, are the most compressible of all matter. It is, in fact, possible to compress 100 cubic feet of air into the bulk of one single cubic foot. The compressibility of liquids, though small, is quite appreciable, and can be measured with suitable apparatus. In the case of water, the compressibility decreases as the temperature rises, and fresh water is more compressible than sea-water. Solids vary greatly in compressibility: glass, under pressure, soon gives way and becomes powder, but wood, cork, and bread are very compressible. In the case of metals, the impression upon a coin shows the gold, silver, or bronze to be compressible,* because the impression is made by pressing the molecules closer together.

Elasticity.—Smear a smooth, polished, flat stone with ink, and let fall on it a marble, catching it as it rises again. The marble touches the stone at only one little spot, yet when we examine the ink on the slab, we find that there is a large circular mark. The truth is that, when the marble struck the stone, it became flattened, and the mark was made on the inked slab while the marble was in that flattened condition. The marble, however, possesses the property of springing back instantly to its original shape, and this springing back gives it its upward rebound. All bodies have the property of springing back to their former shape after release from compression. But just as they vary in compressibility, so do they vary in this property of **elasticity.** Some substances, like sponge, show elasticity after being squeezed; some, like india-rubber, after being pulled or stretched; some, like whalebone, after being bent.

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* The impression upon a coin also shows the slight plasticity of the metal, *i.e.* a displacement of molecules as well as compression.

Liquids are perfectly elastic, as they at once resume their original bulk when pressure is removed.

Indestructibility.—Matter can be changed in form but it cannot be destroyed. Salt dissolved in water has not been destroyed. For if you take a known quantity (by weight) of salt and dissolve it in a known quantity of water, you will find, upon weighing the solution, that it is equal to the weight of the water plus the weight of the salt dissolved. A given weight of ice melts to the same weight of water. Place a few small lumps of ice in a flask and stand the flask on one of the pans of a balance. Counterpoise with shot in the other pan. As the ice melts, notice that there is no change of weight. Also, a given weight of distilled water can be changed to steam, the steam passed through a Liebig's condenser, and if the experiment has been carefully done the distillate will weigh exactly as much as the original distilled water. This property of persistence in spite of apparent destruction is called **indestructibility.**

Divisibility.—Matter of all kinds is composed of minute particles called **molecules.** A molecule is the smallest cluster of chemical **atoms** that can exist by itself. Thus, a piece of chalk consists of molecules of calcium carbonate; but each molecule of calcium carbonate consists of atoms of carbon, calcium, and oxygen. So that, though all matter is extremely divisible, the physical limit is the molecule and the chemical limit the atom.* Drop a small piece of some powerful dye into a vessel of water, and the whole of the liquid may soon, by stirring, be coloured. The least drop of the water, if removed from the rest, would retain the colour. If the vessel contained

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* The chemical limit is not final, since there is the further breaking up of atoms into *ions*, which may be called the electrical limit.

100,000 drops of water, the piece of dye must have been divided into at least 100,000 particles. By this property of **divisibility** we are able to reduce bodies to a required size. It is by this property, too, that rocks are caused to wear away and become mere particles of dust.

Weight.—There is no need to prove that solids and liquids possess this property. It may, however, be difficult to accept the same truth about gases. Take an air-tight, stoppered glass bottle; exhaust all the air from it by the air-pump, and then weigh. Remove the stopper, and allow air to enter the bottle. Weigh again, and you will find it heavier than when exhausted. What makes it heavier is the weight of the air in the bottle. If the bottle holds exactly 100 cubic inches, the increase of weight would be just 29 grains. If we had allowed hydrogen to enter instead of air, the increase in weight would have been only 2 grains. From this we see that even hydrogen, though the lightest of all bodies, has weight. This property of **weight** is not exactly inherent in the body possessing the property, but depends upon the presence of other bodies in the universe. Every material body exerts an attractive force upon every other material body, and a body having more matter in it than another body will pull the smaller mass towards itself. Thus all bodies near the earth, being less in mass than the earth, are pulled towards the earth, and it is this pull that gives to a body the property of weight. Throw a stone up in the air as high as you can. It comes down again. You say that it comes down by its own weight. True, but that is only another way of saying that it comes down because attracted by the greater mass of the earth.

Forces of Nature.—Weight, then, is the pull of the earth upon a body. The amount of matter in the body is known as its **mass.** The strength of the pull depends upon two things: (1) mass, (2) distance. The greater the mass, the greater the attractive force; the greater the distance, the less the attractive force. This uniformity of attractive force is known as the Law of **Gravitation,** and the force itself as the force of **Gravity.*** Mass and weight are not the same thing; for the same mass increases in weight as it nears the centre of the earth, and decreases in weight as it is removed from that point. If ever you have a chance to go up in a balloon or an aeroplane, take with you a small spring balance and something of known weight, say, an iron ring weighing exactly 1 lb. You will find that at a good height above the earth the ring will cease to weigh 1 lb.† Take with you the same things if ever you get a chance to go down a coal-mine, and see what happens to the weight of the ring at the bottom of the shaft. But remember that the mass of the ring remains unchanged. The force of gravity acts between bodies at whatever distance apart, and of whatever kind. There is another force that acts between particles of the *same* kind when they are in close contact. In the manufacture of black-lead pencils, when the powdered plumbago is subjected to great pressure, the particles cohere to form a solid. This force is called **cohesion.** If the particles of the one body be unlike those of the other body, the force that causes them to stick or adhere is called **adhesion.** The sticking of gum to paper or varnish to wood are examples of the force of adhesion. **Chemical affinity** is the attractive force which acts, under certain conditions, between the atoms of one substance and those of another. The combination of atoms under this force results in the formation of a new body. Of these *four forces*, gravity is the only one that acts apart from contact.

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* The Law of Gravitation is usually stated as follows: Every particle of matter in the universe attracts every other particle with a force which varies directly as the product of their masses and inversely as the square of the distance between them.

† Scale pans would not serve the purpose of showing the change of weight, as the weights themselves would also change.

Forms of Matter.—It is a familiar fact that liquid water can be changed by the application of heat into steam, which is a gas, and by the removal of heat into ice, which is a solid. Air, by means of suitable apparatus and methods, may also be made to change from the gaseous form to the liquid. Molten iron and molten lead are familiar examples of metals in the liquid form. Pour some petrol on your hand. Notice that it quickly disappears in an invisible form, showing that it has become a gas. These changes are nothing more than changes of state: liquid air is still air but in a different form, steam and ice are both water in other forms. Such changes are called physical, and they are quite different from chemical changes. Red oxide of mercury is a solid. If you put a little of this substance into a test-tube of hard glass and heat it in the flame of a spirit-lamp or a Bunsen burner, you will see the red powder first turn black, and almost immediately afterwards little globules of liquid mercury will be seen on the cooler part of the tube. In this case the solid red oxide gives off a gas, and part of it has changed to liquid mercury; but the liquid is *not* the red oxide in another form, it is pure mercury without the oxygen. In short, it is not only a change of form but also a change of substance, that is, a chemical change. The process of changing matter physically from one state to another is in many cases quite simple and easy; but in others it requires complicated apparatus and much knowledge and skill. It may, however, be stated as a probability that *all matter is capable of existing in either the solid, the liquid, or the gaseous form.*

Solids.—Solids have a fixed shape, and they resist any attempt to alter that shape; any alteration in shape is always the result of the application of force. This may be easily exemplified by the act of driving a screw into a piece of wood, or by trying to force a wedge of wood between two bricks in a wall, or by squeezing a lump of lead in a vice, and so on. The quality of a solid that causes it to resist change of form is called *rigidity*, which is, after all, but another name for *solidity*. It is due to the cohesion of the particles, and the force of this cohesion has to be overcome when a solid body is broken, split, or cut. The fact that lead is more easily broken than steel shows that the force of cohesion is not equally strong in all solids. The force of cohesion is due to the attraction between molecules, and it increases as the molecules get closer to one another. In solids cohesion is greater than in liquids, and in liquids greater than in gases.

Liquids.—Liquids have no shape of their own; they take the shape of the vessel which holds them, and, except at the edges of the vessel, always have a level surface. The force of cohesion in liquids is slight compared with that in solids, and so the molecules easily move over and away from one another. Hence liquids flow when their support is removed, or, to put it another way, they have *no rigidity*. Take a number of clean glass tubes of fine bore, each open at both ends, and immerse them in water or any other liquid capable of wetting the glass. You will see that the water in each tube rises to a level higher than that at which it stands outside, and that it rises highest in the tube with the finest bore. If you place two plates of clean glass vertically parallel in a dish of water you will see the water rise between the plates higher or lower according as the plates are nearer or farther apart. The liquid rises between the plates only half the height that it rises in a tube whose bore is the same in diameter as the distance the plates are apart. This property of liquids is called capillarity, and the liquid is said to rise by **capillary attraction.** The explanation of the phenomenon lies in the fact that on the surface of liquids there is a kind of elastic skin of liquid which acts in a way quite different from the liquid below. The stretch of this surface skin is due to what is called surface tension, the importance of which will be noticed later in describing thermometers. This elastic surface-skin sticks to the inside of the tube, and pulls the water up the tube until the weight of water raised above the level outside the tube is equal to the force exerted by the skin. Hence, as only liquids that wet the glass can stick to the inside of the tube, it is only such liquids that can suffer this capillary attraction. Mercury, which, though liquid, does not wet the glass, is an exception.* Liquids, like solids, vary as to the amount of cohesion their molecules possess. It is easier to push the hand into a basin of water than into a basin of treacle, because the molecules of the latter have more imperfect mobility than those of the former. Tar is less mobile than treacle, and mercury less mobile than tar. In some liquids the mobility of the molecules is so imperfect that they may be temporarily heaped up, though in time their surfaces will become horizontal. These, like vaseline, thin jelly, or pitch, are called **viscous liquids.** They must be distinguished from soft or **plastic solids,** whose shape is easily changed, such as clay, putty, etc. A soft solid does not *flow*, a viscous liquid does.

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* Mercury is an exception so far as a *glass* tube is concerned; for though it does not wet the inside of a glass tube, it does wet the inside of a copper tube, and so, in the latter case, rises in the tube by capillary attraction. In studying the capillary properties of any liquid three factors must be considered: (1) the liquid, (2) the solid, (3) the gas in which the phenomenon takes place. See any good text-book on Physics.

Gases.—The molecules of a gas are so far from one another that the attraction between them is a minimum. This is why there seems to be no force of cohesion in a gas, and why the molecules are sometimes said to repel one another. The power of spreading, so characteristic of a gas, and so apparent when an escape of coal-gas in the kitchen can be detected in the attic, is called **diffusion.** Gases diffuse much more easily than liquids, and liquids more easily than solids. In fact, diffusion varies inversely as cohesion. Gases may be poured from one vessel to another, *i.e.* they *flow*. Therefore both liquids and gases are **fluids.**

Stress and Strain.—A force acting upon a body tends either to stretch it, bend it, compress it, or twist it. The body in its turn resists this force. The applied force together with the resistance offered by the body is called a **stress.** Any result of such a stress, however little may be the deformation of the body acted on, is called a **strain.** *Stress is a cause; strain is an effect.* There may be stres without strain, as in the attempt to twist a wire which effectually resists; but there cannot be strain without stress.

EXERCISES

1. How can it be shown that there is no loss of matter —(*a*) when ice melts, (*b*) when sugar melts, (*c*) when water boils away?

2. Explain the terms *vertical, horizontal, up, down.*
3. Why does a piece of iron sink in water and float in mercury? And why does an iron ship float in the sea?
4. Explain *cohesion, surface tension, capillarity.*
5. Describe two experiments to show that substances do not lose in weight when they undergo a change of state.
6. How can it be shown that a glass marble undergoes compression when it is allowed to fall upon a hard slab?
7. Describe an experiment to show the porosity of a liquid.
8. What is the difference between adhesion and cohesion?
9. If the sun attracts the earth, why does not the earth fall into the sun? (Camb. Jun. Loc.)
10. Distinguish between viscosity and plasticity, and between stress and strain.
11. What are the other physical forces of attraction besides gravitation?

CHAPTER III

Heat and Light

Conduction.—Put a poker in the fire. Very soon the end in the fire becomes red hot. But the other end has also become hot. This is because the heat of the fire travels along the poker from particle to particle, until it reaches the opposite end.

Put an iron rod and a copper rod in the fire with ends projecting. Hold an ordinary phosphorus match at the projecting end of each rod. The match touching the end of the copper rod fires first. This is because the heat from the fire is more readily transmitted along the copper rod than it is along the iron rod.

Place a strip of copper and a strip of bone in a vessel of boiling water. After a few minutes the projecting end of the copper strip is too hot to hold, while the bone strip is not sensibly heated at all. This is because the heat from the boiling water travels along to the end of the copper strip, but not appreciably along the bone strip.

When heat travels along a substance by moving in all directions from particle to particle, it is said to be *conducted*, or that it moves by **conduction.** Substances along which it moves easily, like metals, are called *good conductors*; those along which it moves slowly, like glass or earthenware, are called *bad conductors*; and those along which it scarcely moves at all, like bone, are called *non-conductors*. As a rule, liquids are not such good conductors of heat as solids are. And among solids, generally speaking, dense substances are good conductors, light porous substances are bad conductors. In conduction of heat the molecules do not move bodily through the substance, but merely pass on the heat from one to another.

Convection.—Take a long test-tube, nearly fill it with water, and drop a piece of ice to the bottom. The ice must first be bound lightly with wire to make it heavy enough to stay at the bottom of the tube. Hold the upper part of the test-tube in a gas-flame. Soon the water at the top will boil, but the ice remains at the bottom unmelted. If heat travelled through water by conduction, the bottom water would have become as hot as the top water; for conduction acts downwards as well as upwards.

Nearly fill a large flask with water, and into it drop a small piece or two of solid blue litmus. Apply heat (by means of a Bunsen burner or spirit-lamp) to the bottom of the flask. Soon you will see an upward, central current in the water, rendered quite easily visible by the blue colouring from the litmus. On reaching the surface this upward current bends over in every direction and forms descending currents along the inner side of the flask. When these reach the heated lower portion of the flask they begin to ascend again as before as an upward central current. The upward current occurs because the flame heats the molecules of water at the bottom of the flask, and becoming lighter as they expand they rise to the surface. That is, in a liquid, the molecules themselves move bodily through the substance of the liquid. But if these heated molecules rise to the surface, the colder molecules from the surface must sink to the bottom to take their place. The heated molecules give out their heat as they rise, and become cold by the time they reach the surface, to return again to the bottom and take the place of some more heated molecules that are still rising. By and by the temperature of the whole of the water has risen, and the rising molecules of water begin to be changed into molecules of steam which now move to the surface more rapidly as aggregations of steam molecules in the form of tiny bubbles. When these tiny bubbles of steam reach the surface without bursting, the water is said to boil. When heat is carried by heated particles moving through the whole mass, the process is called **convection.** (See p. 275.)

Boiling-point.—Boil some water in a beaker, and with a thermometer test the temperature. It will be 212° F. Boil some alcohol and test in the same way. This time the thermometer will not register much more than 170° F. Now boil a solution of salt and water, adding a little more salt after each test. You will find that the more salt you put in the solution, the higher the boiling-temperature will rise above 212° F. In fact a solution containing as much salt as will dissolve in a certain quantity of water (a saturated solution) would register nearly 230° F. Mercury boils at over 600° F. From this you may deduce the law that *the denser the liquid, the higher the boiling-point.** Now take a flask and half fill it with water. Let the water boil over a gas-flame until the space in the flask above the water is filled with steam. Then cork up the flask and turn it upside-down. When the ebullition has ceased, sprinkle some *cold* water over the bottom of the flask. The water in the flask actually starts boiling again. The cold water on the outside of the flask has changed the steam inside into water again, thus creating a partial vacuum and decreasing the pressure within. From this we conclude that with decreased pressure water boils at a temperature below the ordinary boiling-point of 212° F. This is why at the top of a mountain, where the air-pressure is less than at sea-level, water boils at various temperatures lower than 212° F., according to the height of the mountain.

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* A few liquids are an exception to this rule, *e.g.* carbon disulphide and chloroform.

Radiation.—When you stand before a fire you feel heat coming from the fire, and in the sunshine you feel the heat coming from the sun. It is quite clear that heat reaching us in this way, from any source, passes through the atmosphere. But air is a non-conductor of heat; for if it were a conductor the thermometer in the shade would not differ much from that in the sunshine. Therefore, heat passes from one body to another without warming the air through which it passes. This method of heat-travel is called **radiation,** and the body which sends out the heat is called a **radiator.** Light is also said to radiate from its source, because it travels in wavy lines so very nearly straight that they are always regarded as straight lines and called *rays.* To understand accurately the process of radiation of both light and heat a little consideration of the medium is necessary.

Ether.—Space is not empty. That, however, which fills it has none of the characteristics of matter. Though it cannot be perceived by our senses, it not only pervades all space between suns and worlds, but also fills up all spaces (interstices) between the molecules of matter in any form. This all-pervading, ever-present something in which the whole universe is bathed is called **ether.** If this ether could be considered as matter, there would be direct material communication between us and the sun, and we might possibly hear the explosions of gases that take place there.

Ether-waves.—Drop or throw a stone into water, and notice that it forms a centre of disturbance from which waves may be seen passing in all directions. While the wave-motion continues, throw a cork into the water, and notice that it does not move onward, but merely bobs up and down. This shows that wave-motion is not an onward movement of particles. All sounds are impressions made upon the brain by wave-transmission, but sound-waves move only through matter such as air, water, and rock. Light and heat from the sun also reach us as wavy rays, but these travel through the ether only, which is in a constant state of pulsation with vibrations so minute that they scarcely affect the straightness of the rays. The ether-waves or ripples, so infinitely tiny, are not all the same size, although they all move at the same rate. If a little child wishes to keep up with a big tall man walking, he can do so, but the child must take five or six steps to the man's one. Ether-waves take eight and a half minutes to reach us from the sun; some come with relatively big steps, others with very much smaller steps. Now change the idea of a step into one of a ripple or a vibration, and you have the two points of view from which to consider the ether-waves: (1) their rate of travel from source to destination; (2) the rate of their vibrations as they travel. They all travel through space at over 186,000 miles per second; but the number of wavy vibrations along each ray varies considerably, and the ether-waves are classified according to their vibrations per second, because upon this number of vibrations depend the functions of the rays. That is, they may come as light-rays, heat-rays, or X-rays.

Light-rays.—If ether-waves reach our eyes vibrating

400 million million times per second, we get an impression of *red*; a faster vibration would give us *yellow*, faster still, *blue*, and the fastest we can see at all would give us *violet*. If the vibrations were slower than those that give us red light, or faster than those that give us violet light, we should cease to see any kind of light at all. The rays of light that come from the sun come as a *white* light. To find out what white light is, take a three-sided piece of glass called a prism, and hold it in the path of a ray of white light. The white light will pass through the prism and shine upon the wall or screen as a band of colours ranging from red to violet through orange, yellow, green, blue, and indigo. This band of colours is called the *spectrum*, and it shows that white light is simply a mixture of ether-waves of various rates of vibration.

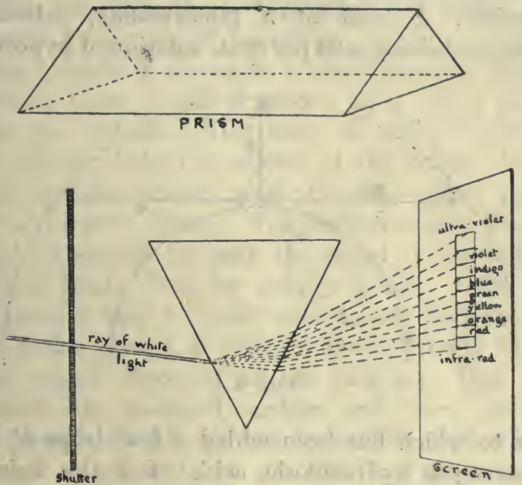

FIG. 1.

Sometimes all the ether-waves that make white light do not reach us. In that case we see colours according to the waves that *do* reach us. In a dense atmosphere, for example, red rays penetrate most easily, and that is the reason we get white light from the sun through the atmosphere at *A*, and a sunset or sunrise light that is red, through the thicker atmosphere at *B* or *C* (fig. 2). Set up a lantern and get as strong and as white a light as possible. Instead of a lantern-slide, introduce a glass cell containing a 20 per cent. solution of hyposulphite of soda to which has been added a few drops of 30 per cent. strength hydrochloric acid. Let the light pass through this solution to the screen, and as the solution becomes more and more turbid by the precipitation of sulphur, the white light changes to yellow, then to orange, then to red, according to the increasing opacity of the solution. The white light on the screen represents the white light from the sun, the yellow, orange, and red represent the light from the sun seen through the thicker atmosphere at sunrise or sunset.

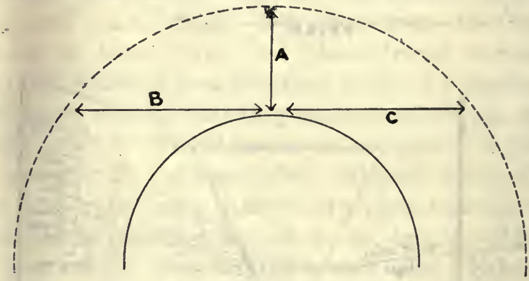

FIG. 2.

Heat-rays.—The ether-waves that vibrate too slowly to give red light are the heat-waves. These slow-vibrating waves come to us from the sun mixed with the light-waves. Both rays of heat-waves (heat-rays) and rays of light-waves (light-rays) are forms of radiant energy. So that **radiation** may be defined as energy propagated by vibrations of ether, the ether being set in vibration by heated bodies. The invisible slow-vibrating radiant energy is known as **dark heat-rays** ; the quick-vibrating, visible, radiant energy is known as **light heat-rays.**

Radiation and Absorption.—A radiator is a heated body which cools by giving off heat-rays. Boiling water will cool more quickly if placed in a vessel painted black on the outside, than it will if placed in a vessel painted white on the outside. This may be easily tested and proved. Again, hold two sheets of tin before the fire, one piece polished bright and the other piece painted black or some dark colour. The radiant energy from the fire will be absorbed by both the metal sheets and converted into heat. But by simply feeling them after a short time it may be easily ascertained that the dark sheet is hotter than the polished one. This is because the dark colour absorbed all the heat-rays that came to it, while the polished surface sent them back, or *reflected* them. Hence we conclude that dark-coloured bodies and rough surfaces are the best radiators and the best absorbers of heat, and vice versa. That is, good absorbers are good radiators, and bad absorbers are bad radiators.

Specific Heat.—Mix two equal quantities of water, one being at boiling-point and the other at freezing-point. Take the temperature of the mixture. It will be 122° F. That is, the boiling water has given up 90° and the cold water has gained the same 90°. Take now two equal weights of mercury and water, the mercury at 212° F. and the water at 32° F. Mix them, and take the temperature of the mixture. It will be 38° F. That is, the mercury has fallen 174° in temperature, whereas the temperature of the water has risen only 6°. If the water had been 212° F. and the mercury 32° F., the temperature of the mixture would have been 206° F. That is, the heat given up by the water would have raised the mercury 174°, though the water fell only 6°. This shows that the quantity of heat which will raise mercury 174° will raise an equal quantity of water only 6°. Hence mercury can reach a certain temperature much more quickly than water, and can cool much more quickly. This is because the mercury cannot hold so much heat as the water, and so can reach the required temperature quicker, and having for the same reason less heat to part with in cooling can cool more quickly. You can understand this more easily if you remember that a boy's stomach has not so great a capacity for food as a man's, and therefore it gets full quicker. Now you will easily see the meaning of the statement that a little heat sends up the temperature of the mercury a long way; whereas much heat sends up the temperature of water only a little way. And so we say that the **specific heat** of water is higher than that of mercury. In the same way, iron can receive much heat without rising so high in temperature as lead which has received the same quantity of heat. Hence iron has a higher specific heat than lead. Bodies, like water, that have high specific heat, take longer to get hot, can hold more heat, and take longer to get cool, than other bodies. Bodies, like mercury, that have a low specific heat rise in temperature very quickly with a very small quantity of heat, can hold little heat, and cool rapidly.

Latent Heat.—When water freezes, it changes from a warmer to a cooler state, and the warmth it had is given out to the atmosphere. This is true always when any liquid changes to a solid. When a thaw sets in after a frost, warmth is absorbed by the solid ice as it changes to water, and this warmth is drawn from everything in the neighbourhood of the ice that has any warmth to give it. This is true always when any solid changes to the liquid state. So, too, when a gas becomes a liquid, heat is evolved; and when a liquid passes to the gaseous state, it absorbs heat from neighbouring objects, making them correspondingly cooler. You will now understand why, during a frosty night, a bucket of water placed in a room will warm the room as the water freezes. You will also understand why allowing damp clothes to dry upon your body (*i.e.* liquid becoming vapour) draws sufficient heat from your body to give you cold. The heat which is hidden in a substance, and which becomes manifested by change of state, is known as **latent heat.**

EXERCISES

1. Distinguish between temperature and quantity of heat, and illustrate the distinction by an experiment.
2. Why are double windows often used in cold countries, and why is a double tent often used in the Tropics instead of a single one ?
3. Why does boiling jam scald worse than boiling water ?
4. Why are several thin layers of clothing better than a single layer equal in thickness to the sum of the thin layers ?
5. How can warm water be made to boil without heating it ?
6. Distinguish between specific heat and latent heat.

What important effects in the economy of nature result from the great specific heat and the great latent heat of water?

7. Why does a cold plate soon become hot when steam from a kettle condenses upon it?
8. Explain why cold water cannot be raised to boiling-point by the addition of boiling water, but can be raised to boiling-point by the addition of steam at the temperature of boiling water.
9. Which is correct to say and why, (*a*) there are different kinds of radiations, or (*b*) different kinds of rays, from an incandescent body?
10. How would you prove that when ice is melted, heat is absorbed without raising the temperature?
11. Take 2 ounces of lead and 2 ounces of water, place them in a beaker, and heat the beaker over a Bunsen flame. Take two other beakers, each containing 2 ounces of cold water, and add the hot lead to the one and the hot water to the other. Stir, and with a thermometer note the temperature in each case. State how the thermometer readings differ and the cause of the difference.
12. Why is the sun considered as the ultimate source of terrestrial energy?
13. Describe the three methods of heat transmission.
14. What is meant by the expression "glass is transparent"?
15. What are meant by *diathermanous* and *athermanous* substances? Give a good example of each. How does the earth behave with regard to radiant energy incident upon it? (Oxf. Jun. Loc.) (See p. 132.)
16. How would you show that an iron bar becomes longer when it is heated?

17. Define the terms conduction, radiation, and convection, and illustrate their meaning by reference to familiar phenomena. (Oxf. Jun. Loc.)
18. Define convection, and describe experiments to show the process by which heat is mainly transmitted (*a*) in liquids, (*b*) in gases. (Oxf. Jun. Loc.)

CHAPTER IV

Reflection and Refraction of Light

Reflection of Light.—Everyone is conversant with the fact that after the sun has disappeared below the horizon and its rays cease to reach us, there follows a period of half-light called twilight. This is because the sun's rays still continue to pass through the upper layers of air above us, and are there scattered and reflected by the clouds and dust particles. This diffused light in time reaches the earth and constitutes **twilight.** The duration of twilight depends upon the height of the atmosphere and the obliquity of the sun's rays to it. It will be seen later on that because of the obliquity of the sun's rays the length of twilight also varies with the latitude. It lasts in our islands until the sun is from 16° to 18° below the horizon. In the tropics where the sun's rays are more vertical, twilight is naturally much shorter, while at the Poles there is only a slight glimmer of twilight each day. The phenomenon of twilight has assisted astronomers in estimating the height of the atmosphere. By means of it they have calculated that the atmosphere extends for 45 miles, but we know from the course of meteors in the heavens that it extends to a far greater distance, possibly 200 miles, although at such a height it may be in a very rarefied form. (See p. 123.) In dealing with the length of day we should be very careful not to confuse reflection with refraction: (*a*) By *reflection* (even in the higher latitudes) the rays of the sun are received after it has disappeared from view. (*b*) By *refraction* the sun is seen apparently above the horizon when it is below.

Refraction of Light.—Light travels in virtually straight lines called rays. But this is only true if the medium through which the rays pass is of a uniform nature throughout. If a ray leaves one medium and enters another, it bends on entering the second medium. This bending, due to the altered rate of travelling of the ray, is called **refraction.** The fact that we can see objects at all is due to the rays of light being reflected from the objects to our eyes. Different coloured objects absorb more or less light according to their colour, and what they do not absorb they reflect to us. White objects absorb nothing, while black objects absorb all. It is for this reason that we are able to recognise the colours of things. In the case of the film of a photographic plate the reflected rays of light act with more or less intensity upon the silver salts in the film, thereby giving less or more transparency to the negative after the affected salts have been acted upon by the developer. Light is propagated by rays (p. 19) through our atmosphere, and the direction in which a ray travels on its way towards the earth depends upon the density of that medium. That rays become broken on leaving one medium and entering another of greater density may be proved as follows: Plunge a pencil into a basin of water and hold it in a slanting position. The pencil will appear to be broken along that line where it leaves the water and enters the air. This phenomenon is due to the **refraction of light.** The rays from the bottom of the pencil, on travelling through the water into the air, pass from a denser medium into one less dense and are therefore bent. Suppose a perpendicular be now drawn to the surface of the water where the pencil enters it, this line is known as the *normal*, and the rays on emerging from the water will be bent away from it. If, however, the pencil be placed in the water, so as to coincide with the normal, that is in a vertical position, there will appear to be no cleavage, and the degree of refraction will be nil. We may, therefore, conclude that rays of light travel in a straight direction so long as they continue in the same medium, but on meeting a new medium they undergo a change in direction, the nature of the change depending on the density of the medium. On entering a rarer medium the degree of bending away from the normal to the common surface is greater than that on entering a denser medium.

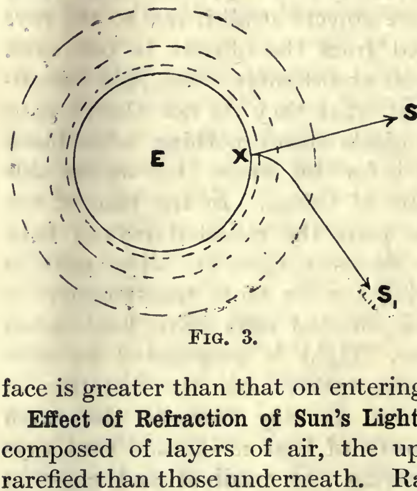

Fig. 3.

Effect of Refraction of Sun's Light.—Our atmosphere is composed of layers of air, the upper ones being more rarefied than those underneath. Rays of light proceeding from the sun will therefore become more and more refracted as they travel through the denser media until they near the earth, where the maximum bending is obtained. Consider the diagram (fig. 3). The line S_1X represents a solar ray refracted as it passes through the atmosphere on its way towards the earth. To an observer at X, the position of the sun appears to be in the same direction from which the ray of light seems to come. He would, therefore, conclude that the sun's direction lay *not* in the direction of S_1, but in that of S. It is because of this we are enabled to explain why the sun may be observed in the heavens for some time after it has actually gone down below the visible horizon. The prolongation of the length of day is likewise explained. Before the sun is visible to us, light is obtained from it; this period of the day is called the **dawn.**

Duration of Twilight.—Let AO (fig. 4) represent light travelling from the dense medium with an angle of incidence AON. A little is reflected, but most of it continues into the rare medium in a new direction OB, so that the angle of refraction N_1OB is greater than the angle of incidence AON. Now let the angle of incidence be increased to CON. Then the angle of refraction N_1OD is greater than CON. As the angle of incidence increases the angle of refraction increases still more, and a position will finally be reached (say EO) when the refracted ray would make an angle of 90° with N_1O, *i.e.* would be refracted along the common surface, *i.e.* would

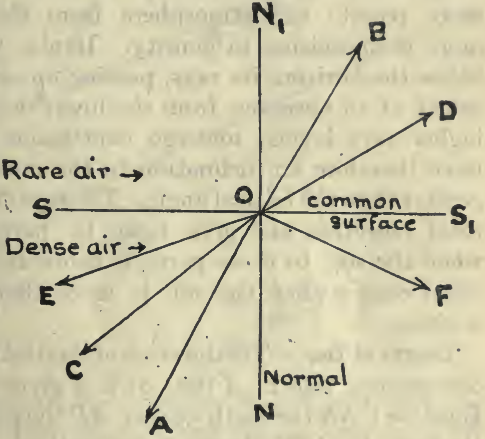

FIG. 4.

not pass beyond the common surface. In this case it would undergo *total reflection* along *OF*, so that the angle of reflection *NOF* = the angle of incidence *EON*. If a ray makes an angle with *ON* less than *EON*, then it is refracted and continues in the new medium; but if it makes an angle with *ON* greater than *EON*, then none gets through, but it undergoes total reflection, coming back into the denser medium again. The angle *EON* is called the *critical angle* for these particular media. Now, the more remote the atmosphere from the earth is, the more it diminishes in density. Hence, when the sun is below the horizon, its rays, passing upwards towards the zenith of an observer, from the lower dense layers to the higher rare layers, undergo continuous refraction, and have therefore an inclination to the normal increasingly greater than the critical angle. The rays therefore undergo total reflection and give light to parts of the earth when the sun, to those parts, is below the horizon. This effect ceases when the sun is more than 18° below the horizon.

Length of Day.—The duration of daylight for any place is determined thus: *A* (fig. 5) is a given place; *EQ* the Equator; *NS* the earth's axis; *AB* the parallel of latitude through *A*; *NOG* the sun's declination.

Suppose the hemisphere *FEANG* be now in sunlight. As the earth rotates, the point which is at *A* at midday is carried from *A* towards *B*, which it reaches at midnight. *H* will be reached at 6 p.m., *K* at sunset. But this period of light is increased by atmospheric refraction and reflection. When the disc of the setting sun first seems to touch the horizon, it is really below it altogether and is only seen by refraction. After the sun has wholly set at any given place, its light still continues to illuminate the upper portion of the atmosphere at that place, so that instead of ending abruptly, daylight gradually fades away until the sun is 18° below the horizon, which takes longer as the latitude increases. Now draw *MI* parallel to *GF* at a distance from it equal to sine 18°. Then, *GBF* being the unilluminated hemisphere, *GMIF* will represent the twilight zone. The point *A* as it moves along the parallel *AB* loses sight of the sun at *K* and is in twilight till it reaches the small circle *MLI*, when the sun's zenith distance is 108° (90° + 18°). The duration of twilight corresponds to the portion *KL* of *AB*, and the time taken to rotate through this will be shorter in low latitudes than in high.

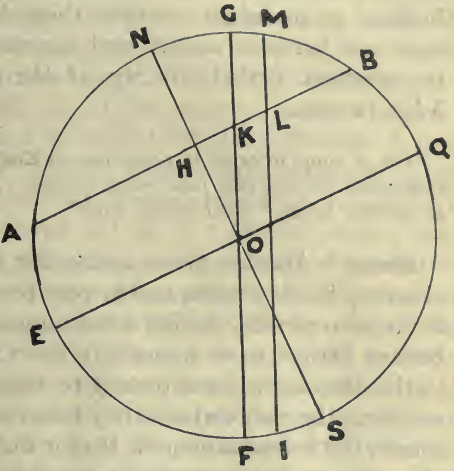

Fig. 5.

From what has been said it is clear that as we proceed north or south of the equator, reflection changes to refraction and the length of day is thereby increased while the length of night is correspondingly diminished. Within the Arctic and Antarctic circles at the summer and winter solstices respectively, the sun does not sink below the horizon at all. At latitude 70°, although near midsummer the sun sinks below the horizon, it never gets 18° below, consequently twilight there lasts from sunset to sunrise. At London in latitude 51½° twilight continues all night from May 23 to July 20. It is shortest about three weeks after the autumnal and three weeks before the vernal equinox, when its duration is 1 hr. 50 min. At latitude 30° the sun is more than 18° below the horizon at midnight, so that there is a period of total darkness between sunset and sunrise. At the equator the shortest twilight occurs at the equinox when it is 1 hr. 12 min.

It is of some interest to note that in England twilight is legally recognised to end one hour after sunset. For vehicles, etc., this is spoken of as "lighting-up time."

Mirage.—Another phenomenon due to refraction may be observed in very warm and in very cool climates, and even in our own country during a hot summer. Travellers in the Sahara Desert have frequently been mystified by seeing in the distance what appeared to them as an oasis. On reaching the point where they believed it to be they have found, to their amazement, that it did not exist. Such a phenomenon is the result of great differences in density in the atmospheric layers due to a great range of day and night temperatures. Suppose first that the layer of air near the earth is uniformly dense, and that a warm stratum lies above it, in which the density rapidly diminishes. Obliquely ascending rays from some distant object will by refraction become nearly horizontal, and so, being incident upon the upper layers of less dense air at angles greater than the critical angle, such rays will be totally reflected and will reach the earth at some distant point. But often the rays from the top and the bottom of the object cross one another in the warmer stratum, so that the observer at the distant point seems to see the object suspended in the air upside-down. This may happen while the observer sees the object itself by direct vision through the lower air. Next, suppose that the layer of air near the earth is very warm, and that a cooler stratum lies above it in which the density is greater than that of the lower layer. Rays of light from the lower parts of the sky, as they pass through the denser upper air, being by refraction incident upon the lower layers at angles greater than the critical angle, will be reflected upwards. The eye of the observer, in this case, receives an impression resembling that produced by the reflection of skylight from water. If the lower warm stratum of air flickers by reason of convection currents in the stratum, the impression received is that of a breeze playing over the surface of the imaginary water. Each of these two optical illusions is known as a **mirage.** The second of the two illusions is confined to the arid deserts of the world. The first kind of illusion occurs in all parts of the world. It is specially common in high latitudes at sea. In the Arctic regions it is no uncommon occurrence for whale-fishers to discover the proximity of other ships and of icebergs by seeing their inverted images suspended in the air, though the objects themselves may be below the horizon.

Another form of mirage is the *Fata Morgana*, which may at times be observed in the Strait of Messina. In this case, objects on the opposite shore seem to be unduly elongated in a vertical direction. This is due to the existence of a horizontal stratified medium of maximum refractive index through which the object is really viewed. Above and below this layer of air are strata of decreasing refractive power. Consequently the conditions of the distribution of density act as a continuous lens magnifying the object in a vertical direction. Imagine the same atmospheric conditions to prevail in a vertical as well as a horizontal plane: we should then have the object magnified both vertically and horizontally. This is frequently the case at sea in foggy or misty weather, and the phenomenon which results is known as *looming*.

EXERCISES

1. How are the images of trees, houses, clouds, etc., formed in smooth water?
2. Why is it that when you look vertically down into transparent water, it appears shallower than it really is?
3. How is it that in the daytime we are able to see objects that receive no direct sunlight?
4. Prove that when a mirror rotates, the angle through which the image moves is twice the angle through which the mirror moves. What is the practical value of this proof? (see Chap. VIII).
5. Why do grapes out of doors in England grow best on a black wall facing south?
6. Twilight lasts all night in London from May 23 until July 20. Explain fully the meaning of this statement, and account for the facts. Compare it with what happens at (*a*) Madeira and (*b*) the Shetland Islands. (Oxf. and Camb. Lower Cert.)
7. Explain the cause of twilight. At what period of the year is there no true night in London? Why is this? How does the phenomenon of twilight differ in tropical and temperate regions? (Oxf. Sen. Loc.)
8. Explain why the days are longer in the north of Scotland than in the south of Ireland during summer, and shorter in winter.

CHAPTER V

Electricity and Magnetism

Electrical Energy.—We have learned in Chapter III that the sun sends out wavy rays of light and heat, which wavy rays are so near being straight lines—the undulations or vibrations are so minute—that they are always regarded as straight rays. We have now to consider some other rays that ripple with their tiny pulsations through the ether from the sun to the earth. There are rays, called X-rays, that have faster vibrations than those of light and heat, and there are others whose vibrations are slower. It is those which have the slowest vibrations of all that we are now to consider. They are called "Hertzian" waves, after their discoverer. Their energy, quite distinct from heat or light, is electrical, and they are sometimes named electrical rays. Remember that the time taken for either X-rays, light-rays, heat-rays, or electrical rays to reach the earth from the sun is the same, about 8½ minutes. The X-rays make most vibrations in the journey, and therefore their vibrations are inconceivably minute. Rays of light have vibrations less than $\frac{1}{30000}$ of an inch in length. The Hertzian, or electrical, rays have vibrations thousands of feet in length. Electricity is often spoken of as a fluid. This is, of course, a mistake. Electricity is no more a fluid than is light or heat, but, like light and heat, is a form of radiant energy. Heat may be transmitted from matter at a high temperature to matter at a low temperature. In the same way, electricity may pass from a body highly charged with it to another body less highly charged. In such a case the electricity is said to pass from a high potential to a lower potential. Moreover, just as heat is transmitted more readily through one substance than through another, so is electricity. Thus there are good conductors, bad conductors, and non-conductors of electricity, as well as of heat. The passage of electricity, whether along a wire or through the air along the Hertzian rays, is called an electric current. Electrical energy can decompose chemical compounds into elements, and can also unite chemical elements into compounds.

Electricity.—Nothing is known with certainty as to the true nature of electricity beyond the fact that it is a form of energy. We know that electricity can be neither created nor destroyed; that the world is full of it; that more may be caused to appear at one place and less at another, that is, that its distribution in the world may be altered; and that it may be changed from a condition of rest to one of motion. Many appliances, such as batteries, dynamos, and frictional machines, are said to *make* electricity; but they do not make, they merely *collect*, by friction or by chemical action, the electricity that already exists. When the amount of electricity collected on the surface of a body—electricity always resides on the surface—increases, that body is said to rise in potential, and when the potential is sufficiently high, the electricity may be transmitted to some other body whose potential is lower. Dry air is such a bad conductor of electricity that it is called a non-conductor. Yet, given a sufficient difference of potential, electricity can force its way across an interval of dry air. In such a case the energy of the electricity is expended in overcoming the resistance of the air, and is converted into heat or light according to the less or greater effectiveness of the resistance.

Lightning and Thunder.—If between two points of different potential a non-conductor or insulator be interposed, there is no transference of current. If the insulating material breaks down or is removed, sparking takes place. The best known insulator is dry air, and when, under high pressure of potential, this breaks down, the spark is visible as a flash of light. Lightning is a good example of this. The electric potential of a cloud increases as more and more particles of cloud-moisture unite to form the rain-drops; for the surface of a big rain-drop is smaller than the united surface of the particles that aggregate to form it, and there is as much electricity on the one drop as there was on the tiny globules of water-dust.* When, therefore, there is a heavy rain-cloud in the sky with dry air between it and the earth, we have all the elements necessary for sparking on a grand scale. If the difference of potential between the earth and the cloud is sufficiently high to break through the resistance of the air, the current will be converted into heat, and the air-particles in the track of the current will become white hot. The current passes so rapidly from the high potential (cloud) to the low potential (earth), that the sparking takes the form of a flash of lightning. The intensely heated air expands as the flash passes through, contracting again immediately. This sudden expansion and contraction sets up in the air waves of great amplitude along the line of the flash. But waves of alternate compression and expansion produce the sensation of sound on striking the ear. This sound is called *thunder*. Sometimes the sparking takes place from cloud to cloud, giving a different direction to the flash. The kind of sound the thunder gives depends upon the direction of the flash with regard to the hearer, and also upon his distance from the line of flash. As sound travels *during a thunderstorm* at ordinary temperature at about 1,125 feet per second, and as the fraction of a second that light takes to travel a few miles may be neglected, the number of seconds between the flash and the arrival of the sound is a fair indication of the distance of the storm-centre from the point of observation. A fifth of a mile for every second between the flash and the thunder is a near enough estimate. Rain falling from a cloud brings down the electricity from the cloud to the earth again, and so equalises the potentials. Hence thunderstorms with heavy rain are usually short.

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* It is probable that the electricity with which the clouds are charged is derived from evaporation going on at the earth's surface, the vapour acting as a conductor from the earth to the cloud-locus.

Lodestone.—The metal iron in combination with the gas oxygen forms iron oxide. There are several oxides of iron, each containing the two elements in different proportions. One is the black oxide known as **magnetite** or **lodestone.** Magnetite is the general name for all black oxide of iron ; but when the magnetite is found to have magnetic properties, it is called lodestone. Lodestone is very plentiful in Scandinavia and Spain. If a bar of lodestone is cut or shaped so that there is no visible difference between one end and the other, the ends will nevertheless differ considerably. Take such a bar and suspend it by a thread tied round the middle. Notice that, however you arrange the bar, or however you swing it about, it always comes to rest along a certain line. Notice also that if you mark one of the ends with chalk, that end always points in the same direction. This line of direction is a north-south line, and we will suppose that the marked end is the one pointing to the north, hence called the north-pointing end. Now take a second bar of lodestone, suspend it, and find and mark its north-pointing end. Suspend the two marked bars together, bringing the marked end of one towards the marked end of the other; then bring together the unmarked ends of both; then the marked end of one and the unmarked end of the other. Notice that in the first and second cases, as soon as the ends are near enough, it requires a distinct effort on your part to make the bars touch each other. There is a force driving the one away from the other. We say that the one *repels* the other. In the third case, however, as soon as the ends are near enough, you feel the bars make a distinct jump towards each other and stick together. Here, then, is no repulsion; for this time an effort will be required to separate them. Unlike ends have the tendency to attract each other, to leap towards each other; like ends have the tendency to repel each other, to get as far from each other as possible. This uniformity of action, that unlike ends or poles attract and like poles repel, is called the **Law of Magnetic Attraction.**

Artificial Magnets.—The magnetic properties of the lodestone may be transferred to any piece of steel. Take a large darning-needle and stroke it from point to eye with the lodestone. Stroking from eye to point will do just as well, but stroking both ways will be no good, so take care to lift the lodestone at the end of each stroke. Then by doing with the needle what you have just done with the lodestone—(1) get its permanent line of direction; (2) mark its north-pointing end; (3) bring it end to end in the several ways with a lodestone bar—you will find that you have made the needle into a magnet. But remember that attraction alone is not the test for a magnet; there must be repulsion of like poles.*

The Compass-needle.—Procure a compass-needle. This is merely a magnetised strip of steel, pointed at both ends, with the north-pointing end marked. Test the needle by the instructions in the last paragraph; you will notice that its north-pointing end is repelled by the north-pointing end of the magnet, and attracted by the south-pointing end, and vice versa. Now lay a bar magnet on a table and arrange the compass-needle upon it (fig. 6). Change the direction of the needle several times, and notice that it always returns to rest along the line of the magnet, but with its marked end over the unmarked end of the magnet.

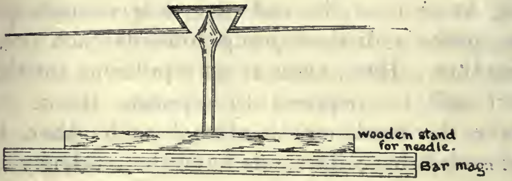

FIG. 6.

Terrestrial Magnetism.—Because of its rotation the earth possesses the properties of a huge magnet, and so acts upon a compass-needle exactly in the same way as the bar magnet did in the last experiment. The poles of the earth-magnet do not coincide with the poles of the axis of rotation; or to put it another way, the magnetic poles do not coincide with the geographical poles, though they are very near.

Declination of the Compass-needle.—Take a good-sized ball (an Association football will do very well), and mark the position of the geographical or true North and South poles by a chalk dot in the middle of the two round pieces of leather which you will find at the convergence of the seams. The seams themselves will represent very nicely the geographical meridians as they go from pole to pole. Now mark a dot about 2 inches from one of the poles (which we will suppose is the north geographical pole) and call the new dot the north magnetic pole. Make another dot about one-third of the way down one of the seams, and call this the observer's position. A line drawn from the observer's position to the north pole will be the observer's geographical meridian; a line drawn from the observer's position to the north magnetic pole will be the observer's magnetic meridian. Notice that there is almost sure to be an angle formed by the intersection of the two meridians. This angle is called the **declination of the compass-needle,** or by sailors the **variation of the needle.** Now clean the football of all old chalk marks and upon it draw a very rough map of the world; *i.e.* just roughly indicate the positions of the continents, the shape does not matter much. In the middle of the north coast of North America mark the north magnetic pole, and two-thirds of the way between the south coast of Australia and the south pole mark the south magnetic pole. Test certain points on the surface of your model earth to see how great or how small is the angle of variation. From each point chosen draw first a line to the *nearest* magnetic pole, and then a line to the corresponding geographical pole. Test, for example, such places as Vancouver, New York, London, Calcutta, or Port Arthur (Manchuria). You will soon discover two things. One is that sometimes the magnetic meridian lies to the right (east) of the geographical meridian, and sometimes to the left (west). The other is that the angle varies in size, being sometimes actually 0°. The conclusion is that the earth may be considered as consisting of two magnetic portions (not exactly hemispheres, since the straight line joining the magnetic poles is not a diameter), in one of which the compass-needle is deflected eastwards and in the other westwards. The boundary line between these two parts is not exactly a circle, although it passes round the earth from one magnetic pole to the other. It is called the **agonic line,*** and along it there is no variation of the needle. So you will see from your globe that, roughly speaking, Europe, Africa, and the Atlantic form the region of westerly variation; while Asia, the Americas, and the Pacific form the region of easterly variation. Lines on a map joining the places that have the same variation of the needle are called **isogonic lines.**

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* A magnetised bar of steel is sometimes bent round into the form of a horse-shoe.

Magnetic Dip.—Besides the eastward or westward declination of the needle, there is another. Lay a large bar magnet on a table, and above it suspend by a silken thread a small magnetised needle. First allow the needle to hang over the centre of the bar at a height above it a trifle more than half the length of the needle, in which position the needle will be horizontal. Then move the suspended needle towards one end of the bar magnet, and notice that one end of the needle begins to dip down until at the end of the magnet the needle is vertical. If the movement was towards the north-pointing end of the bar, it would be the south-pointing end of the needle that dipped, and vice versa. The same effect can be produced by moving the bar magnet under the suspended needle. Now let the earth take the place of the magnet, and suppose a compass-needle to be moved from somewhere near the equator towards the north magnetic pole.

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* Agonic = without an angle.

In most of the northern hemisphere the north-pointing end of the needle dips down, and in the southern hemisphere the south-pointing end of the needle dips down. At the magnetic poles the needle will dip vertically with the appropriate end downwards, the dip becoming less and less as the needle is brought farther and farther from these poles. There is a line lying between the north-dipping and the south-dipping parts of the earth along which neither end of the needle dips, a line answering exactly to the centre of the bar magnet. This line is the **magnetic equator.** For certain reasons, partly a slight movement of the magnetic poles and partly geological changes in the earth's crust, the amount of declination and of dip varies from time to time at the same place. It is by the dip of the needle that the position of the magnetic poles is indicated.

The Magnetic Poles.—The north magnetic pole was in 1831 discovered by Sir James Ross in the peninsula of Boothia, North America, in lat. 70° N., long. 97° W., just over 1,000 miles from the north geographical pole. The south magnetic pole was discovered by Sir Ernest Shackleton's northern sledge-party on January 16, 1909, in lat. 72° S., long. 155° E., the Union Jack being hoisted there at 3.30 p.m. on that day. At the north magnetic pole it is the north-pointing end of the needle that dips, therefore the magnetism of that pole must be south-pointing. Contradictory as this may seem, it does not really matter what kind of magnetism it may be at the pole; it only matters that you should remember that the pole towards which the north-pointing end of the needle is always directed is *called* the North Magnetic Pole, and the other is called the South Magnetic Pole. Therefore, although at the north magnetic pole there is south-seeking magnetism, the north end of the needle points to the north; and similarly with the south magnetic pole.

The Auroræ.—In the polar regions occurs a beautiful magnetic phenomenon known as the Aurora.* In the northern latitudes it is called *Aurora Borealis,* in the southern the *Aurora Australis.* It has the appearance of a dark segment of thick cloud, rainbow-shaped, resting on the horizon. This dark segment is fringed along its upper edge with a luminous arch of white, tinted with green, crimson, violet, and other colours. This luminous arch is part of a luminous ring, the lower part of which is hidden behind the horizon. The centre or vertex of this ring is exactly over the magnetic pole, is sharp-edged on the inside, and on the outside expands and shrinks, giving off rays of coloured light which flutter, wave, and shimmer in all directions outwards, forming most beautiful ribbons, drapings, and streamers. The auroral displays sometimes last for several hours, and are, of course, best and most easily seen in those regions that lie nearest the magnetic poles. In North America east of the Rockies they are quite easily seen as far south as the fiftieth parallel of latitude, and the average number observed is about three good displays per fortnight. In Northern Europe and Asia the same average of good displays is to be seen, but only at places within the Arctic Circle. In North Scotland and in Northern Europe and Asia generally, as far south as the sixtieth parallel a few good displays may be seen, but at this distance from the centre of activity much of the brilliance is lost. The average for this more southerly belt is about forty displays per year. The best place in the British Isles for seeing the displays is the Shetland Islands (where they are called the "merry dancers"), and the best time to see them is the month of October. They are sometimes dimly visible as far south as London (where they are called the "northern lights"), with occasional displays of some brilliance to the extent of an average of two per year.

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* Plural, *auroræ.*

Auroral Theory.—There can be no doubt now that the auroræ are electrical manifestations of some kind. Of the many theories propounded to account for them, the following two are the most important. In the first theory electricity is supposed to ascend in the torrid zone during inter-tropical evaporation and flow to the poles. Here it comes in contact at the magnetic poles with electricity of a different potential, and this gives rise in the rarefied atmosphere which prevails there to the electric discharges known as auroræ. The second theory is that they are due to solar radiation. This explanation is more generally accepted, though it is quite likely that the real truth is a compound of the two theories. If you have ever seen a display of radiant energy by a speck of radium, you will very easily understand the second theory. This rare metal, radium, has the property of sending forth from itself a continuous shower of invisible particles more minute than anything else in nature. Though ordinarily invisible, they affect a photographic plate just as sunlight does, and they may be made visible by placing in their path a piece of zinc sulphide. Similar minute particles are flashed off from incandescent carbon, and such showers of them are shot off from the glowing carbon in the mass of the sun, that the whole of space is filled with them, and our earth is bathed in them, or, perhaps more accurately, is bombarded by them; for they rush at the earth and past it at the rate of several thousand miles per second. These marvellous little particles—a thousand together are scarcely equal in size to an atom of hydrogen —because they are electrical, and are attracted by the common magnet, are called **electrons.** These solar electrons, as they enter our atmosphere, become visible; for when they strike the upper layers they are drawn towards the two magnetic poles, where they act upon certain mysterious gases that exist only there, and so produce the coloured lights of the auroræ.

EXERCISES

1. What reasons have we for believing that the earth is a magnet?
2. If a magnetic needle be supported so as to move only in a vertical plane, what changes would be noticed if it were carried from the south to the north pole and always kept in the plane of the magnetic meridian?
3. Describe the mariner's compass and its chief uses. What do you suppose would happen to the compass-needle if you held the compass tightly in your hand as you walked up a spiral staircase?
4. What is the aurora borealis? Where is it best seen and what is its general appearance?
5. What is the cause of lightning and thunder? Describe a lightning-conductor.
6. Give an account of the variation of the compass in different parts of the northern hemisphere. (Oxf. and Camb. High. Cert.)
7. Define the magnetic meridian at a given place. At what places is the dip (*a*) zero, (*b*) 90°? (Oxf. Jun. Loc.)

CHAPTER VI

The Solar System and the Universe

The whole universe of sun, moon, stars, and planets is mighty almost beyond comprehension. But take a large sheet of drawing-paper and upon it draw the following scheme (fig. 7). From it you may get a working notion of the meaning of the things you see in the sky day by day and night by night, together with some idea of the reasons for their many temporary changes and disappearances. First divide the paper into squares by faint

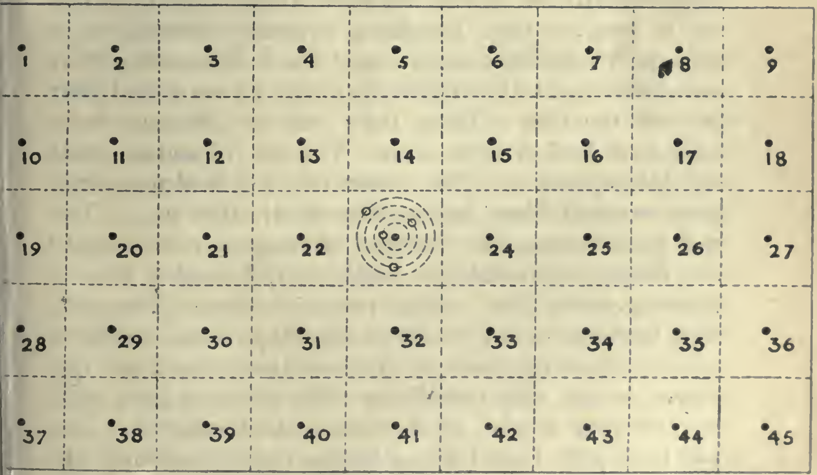

Fig. 7.

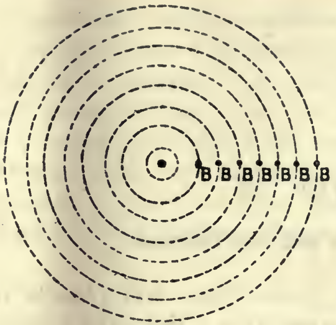

Fig. 8.

pencil lines 2 inches apart, and consider each square to represent a field or meadow in the middle of which a big bonfire is burning. Mark the bonfires with dots in the middle of each field and number them. Select the field in the middle of the paper, and imagine that you and seven other boys are going to play in that field. Suppose No. 23 to be the field selected. You and your companions, each accompanied by one or more dogs, will go into that field and will draw eight circles round the bonfire at different distances from it. Then you will all take up positions (*B*) as in the diagram above (fig. 8). You are to imagine that you have received instructions to spin on your toes (waltz) round the bonfire along your own circle and to train your little dog to run round your feet all the time. Those boys who can manage them may have two or three dogs. You see, of course, what all this represents. The bonfire in your field represents your own sun, those in the other fields other suns. You and your companions waltzing along your circles round the bonfire represent the earth and the other planets spinning along their orbits round the sun. The little dogs that run round your feet as you go along represent moons. You, representing the earth, will have one dog only. As you spin round you will sometimes have your face to your bonfire (day position) and sometimes you will have your back to your bonfire (night position). In the day position you will see nothing but your own sun (bonfire); in the night position you will be looking out amongst the other suns (bonfires), which is just what you can do every night, for the stars you see in the sky are suns. It is quite possible that you may sometimes be able to see one or more of your companions (planets) even when you are in the night position with your back to your own bonfire, provided they happen to have waltzed far enough along their respective paths (orbits) to be between you and other bonfires. This explains why you may sometimes see one or more planets at night as well as the host of stars. Furthermore, the suns (stars) you see when you are in the night position at one point in your orbit will not be the same as those you see in the night position at another point in your orbit. This explains why you do not see the same stars in the summer sky as you do in the winter sky. The little dog, quite close to your feet all the time, makes it easy to understand why you see the moon at night nearer to you than the stars or the planets.

The Sun.—The sun, the largest and most important body in our solar system, is the centre of all the movements of that system. Its diameter is more than 100 times as long as that of our earth. Indeed, so large is the sun compared with the earth, that if the earth could be placed at the centre of the sun, and the moon could there revolve about the earth in its proper orbit, there would still be 190,000 miles to spare between the sun's surface and the moon's orbit. The distance of the sun from the earth, about 93,000,000 miles, may easily give us a wrong impression of its size. How much farther away must be the stars, which are really suns as large as ours! The sun has been radiating light and heat into space unceasingly for millions of years. The heat from the sun warms the surface of the earth, causes the winds and the ocean currents (as we shall see later). The light of the sun gives to plants the power of using the carbon from the carbonic acid gas that we breathe out, and of giving back to us fresh oxygen to breathe in. In fact we owe to the sun all our food, clothing, light, heat, and every form of energy.

The Planets.—Revolving round the sun at different distances, all in the same direction, counter-clockwise, are a number of bodies like our earth, called planets.* Counting from the sun outwards, they are Mercury, Venus, Earth, Mars,† Jupiter, Saturn, Urănus, and Neptune. Each planet rotates on an axis as the earth does, and each except Mercury and Venus has one or more moons revolving round it. **Mercury** and **Venus** being between the orbit of the earth and the sun are called interior or inferior planets; the others are called exterior or superior. Both Mercury and Venus may sometimes come in a direct line between the earth and the sun, and at such times, by means of a telescope with a darkened glass, they may be seen to cross the disc of the sun as a small black spot. This is called a **transit** of Mercury or of Venus. **Mars** is a planet not unlike our earth, but it has been losing its atmosphere and its water much faster than our earth has. It is sometimes supposed that some kind of intelligent beings inhabit this planet, and that these beings preserve and use their scanty water-supply by means of a wonderful system of channels or canals which form a complete network over the whole surface of the planet. **Jupiter** is the largest of all the planets, has eight satellites (moons), and takes twelve of our years to complete a revolution round the sun. When seen through a telescope, belts of cloud are visible on its surface parallel with its equator. These indicate that the planet has not yet cooled down to the temperature of the earth. **Saturn** takes over twenty-nine of our years to make a revolution of the sun. In addition to having ten satellites, it is surrounded by a system of rings consisting of a swarm of meteorites revolving round it. **Uranus** and **Neptune** take 84 and 164 of our years respectively to revolve once round the sun.

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* From the Greek *planētēs*, a wanderer, because planets appear to wander among the fixed stars.

† Between Mars and Jupiter is a ring of about 300 small planets or asteroids.

Comets and Meteors.—The whole of space is filled with fragments of solid matter varying greatly in size, but on the average somewhat larger than a good-sized pea. As the earth revolves round the sun, many of these fragments enter the earth's atmosphere with enormous velocity. The friction of the air upon the rushing particles (meteors) develops enough heat to render them luminous. They begin to glow at a height of about 200 miles, and die out at a height of about 50 miles above the earth. Sometimes, when a fragment is rather larger than usual, it does not wholly melt and vaporise; but a portion of it, known as a **meteorite,** reaches the earth. Meteors revolve around the sun in swarms along very eccentric orbits, and the earth sometimes passes right through a swarm. This occurred on November 13, 1866, and the only sign we, on the earth, had of the fact was an unusually fine shower of "**shooting stars,**" as these meteors are often called. If, in a swarm of meteors, there is a part where the particles are packed very thickly together to form a sort of head, such a swarm is called a **Comet.***

Hundreds of meteoric swarms are always revolving round the sun, sometimes in the same direction as the revolution of the planets (*direct* or counter-clockwise), and sometimes in the opposite direction (*retrograde* or clockwise). Only those swarms with the distinctly bright dot of condensed light for the head, and with the dimly luminous cloud trailing behind for a tail, are called comets. They travel in long ellipses inclined at all sorts of angles to the plane of the earth's orbit. Many enter our system, are seen by us for a short time, and then disappear for ever. A few have their orbits calculated and can be depended upon to return at definite intervals. At the greatest distance from the sun at which they are visible they are very little more than an indefinite mass of luminous mist. As they approach the sun, the characteristic structure of the comet seems to develop in them, the head is seen to shine brilliantly and the tail to stream out away from the sun for millions of miles, the whole making some such appearance as would be made by a mighty rocket rushing through the air so far away that it looked like a slowly moving, long streak of light. Most of the comets whose appearance can be predicted have names, from their discoverers. Halley's Comet was the first to effect a predicted return in 1759, it appeared again in 1835, and again as lately as 1910.

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* From the Latin *comētes*, a comet, from the Greek *komē*, hair. The name refers to the so-called "tail" or "hair" of the comet.

The Stars.—The sun with its family of planets and their satellites, plus the swarms of meteors and comets, forms one system. Beyond, in the far outer expanses of space (remember the bonfires in the other fields), are other suns, but so tremendously distant that the most powerful telescope cannot magnify the nearest of them to anything more than a big dot of light. These are the stars that "twinkle" in the sky; planets, being so much nearer to us, and not being incandescent bodies, do not twinkle.

Planes.—A plane surface is one such that a straight line joining any two points in it lies wholly in that surface. The instrument that makes surfaces plane is called a plane. The top of a billiard-table is a good example of a plane surface, so is a sheet of ice on a still pond, so (usually) is the sheet of glass forming a shop-front. It is often necessary, however, to imagine a surface upon or in which some body moves. For example, when a pendulum swings, it swings in a vertical plane, *i.e.* cuts through the air in an *imaginary* plane surface. If you move your arms up and down like railway signals, you will be moving them in a vertical plane; if you move them as you would in swimming the "breast-stroke," you will be moving them in a horizontal plane. If you fasten a stone at the end of a string you may swing it with a circular movement in any of the directions shown above (fig. 9).

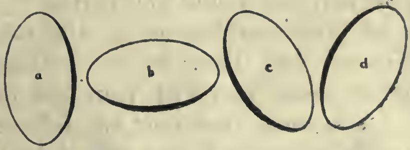

Fig. 9.

In the case of *a* you would be swinging your stone in a vertical plane, in the case of *b* in a horizontal plane, in *c* and *d* in oblique planes.

The Moon.—The earth has but one satellite, which we call the moon. We see the moon as a luminous body because it reflects back to the earth the light it receives from the sun; if we were on the moon we should probably see the earth as a luminous body reflecting the sun's light in the same way. The moon is much smaller than the earth, its diameter being to that of the earth as 1 is to 4, and its bulk to that of the earth as 1 is to 64. It has no atmosphere; for if it had, its outer edge would be blurred instead of sharp; and further, it has no water. It revolves round the earth once a month. The number of days in one revolution depends upon whether we time it from one star round to the same star again, or whether we time it from the sun. In the former case we have the **sidereal** month of 27⅓ days, in the latter case we have the **lunar** or **synodic** month of 29½ days. The **calendar** month is an arbitrary grouping of days so that 12 such groups shall make up 365 days.

Revolution of the Moon.—Any night when the moon rises, note its position with respect to some star. Next night and on following nights, again note its position with respect to the same star. You will notice that each night it gets farther and farther from that star towards the eastern quarter of the heavens. This is the proof that the moon revolves round the earth.

Place one of your companions in the middle of an empty floor-space, and then by a shuffling side-step move completely round him with your face towards him all the time. You must then note the following things:

1. You have revolved once round him.
2. You have in turn faced every point of the compass. That is, you have done something which is equivalent to rotating on your own axis once, while revolving round your companion once.
3. Your companion never had a back view of you.

This experiment will make you understand that the moon rotates once while revolving once round the earth; and the fact that we always see the same side of the moon is the proof of it.

Phases of the Moon.—The different changes in the appearance of the moon as it goes round the earth are called the **phases** of the moon. Take a cricket ball and paint one-half of it white, and let the white hemisphere represent that side of the moon receiving light from the sun (fig. 10). Let this painted ball be moved round the class with its painted face always in the direction of some object representing the sun. While this is being done, the boys of the class should, during a pause of the ball in each of the eight positions, draw in succession

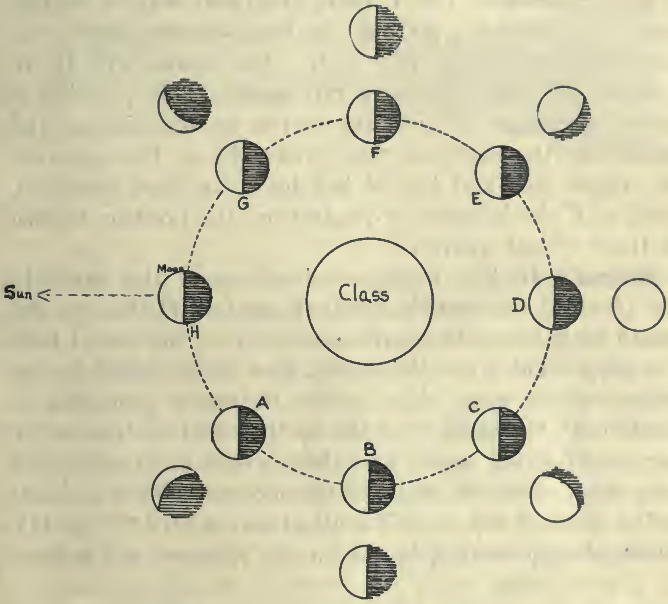

Fig. 10.

along a circular orbit the shape of the painted face they can see. It will be found that the shapes so drawn are like the figures shown in the diagram. This experiment will explain the changes in appearance from one new moon to another. At position *H* the sun and moon are said to be in **conjunction.** In this case the observer on the earth (represented by the class) is unable to see the moon because its dark side is turned towards him. We say it is then **new moon.** About four days after, it reaches position *A*, and the earth-observer sees the moon as a crescent. From night to night the luminous portion seen grows bigger and bigger (waxing). At position *B* it is in **quadrature.** At *C* more than half will be visible, and this is called a **gibbous** * or hump-backed moon. A fortnight after new moon (*H*), the moon will be in position *D*. She is now a **full moon.** This position is called **opposition,** because the sun is on one side of the moon and the earth on the other. From this position she shows less and less of her luminous face (waning), until at *F* she is again in quadrature, the position known as third or last quarter.

Eclipses.—If the moon revolved round the earth in the plane of the earth's orbit, at position *H* (fig. 10) she would be between the earth and the sun, she would hide the sun's light from the earth, and there would be an eclipse of the sun. Also, under the same condition at position *D*, the shadow of the earth would be thrown by the sun upon the moon, and there would be an eclipse of the moon. But the plane of the moon's orbit is inclined to the plane of the earth's orbit at an angle of 5° (fig. 11). Hence at opposition, M_1, the moon receives and reflects to the earth the light of the sun because it is above the earth-plane; and at conjunction, the moon, being below the earth-plane, does not come between the earth and

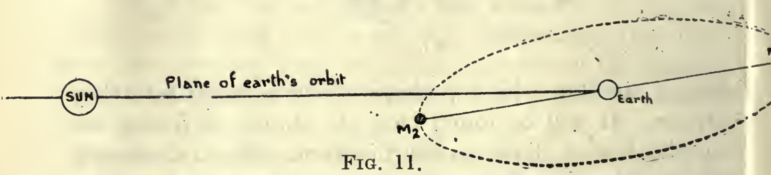

FIG. 11.

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* "g" hard.

the sun. Let us, in imagination, follow the earth along its orbit round the sun, commencing when the moon is in conjunction at its maximum angle of 5° **below** the earth-plane, and in opposition at its maximum angle of 5° **above.** At the next conjunction and opposition, one lunar month later in each case, the moon will have passed its maximum angles and will now be only 4° above and 4° below respectively. At the end of about the sixth month the maximum angle of 5° occurs in the first and last quarters (quadrature) instead of at conjunction and opposition; while at conjunction and opposition the moon-plane actually cuts the earth-plane. The points at which the planes intersect are called **nodes,** and it is then that eclipses can and do occur. Twice every month the moon is at a node. But it is only conjunction and opposition nodes that give eclipses: conjunction makes possible an eclipse of the sun, opposition an eclipse of the moon. The nodes at conjunction and opposition may occur as many as three times in a year.

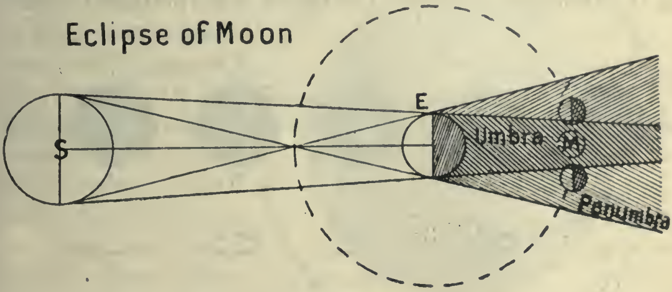

FIG. 12.

Lunar Eclipses.—The dark shadow cone on the side of the earth remote from the sun is called the *umbra* (fig. 12), the half-shadow surrounding this cone is called the *penumbra.* The moon (M) is eclipsed during the time it takes to pass along its orbit through the umbra cone. It is obvious that the nearer the moon is to the earth at the time of the eclipse the longer will she take to pass through the shadow. The diagram above (fig. 13) explains why the opposition node gives a total eclipse of the moon; opposition nearly at a node gives a partial eclipse, and opposition not near a node gives no eclipse.

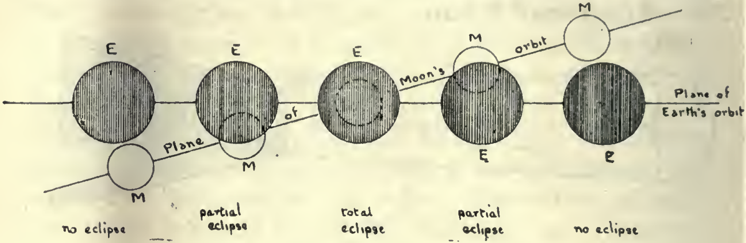

FIG. 13.

Solar Eclipses.—The sun is eclipsed when the moon in passing directly between us and the sun temporarily screens off the sun's rays. It will be seen from the diagram (fig. 14) that the lunar *umbra* does not cover the whole earth.

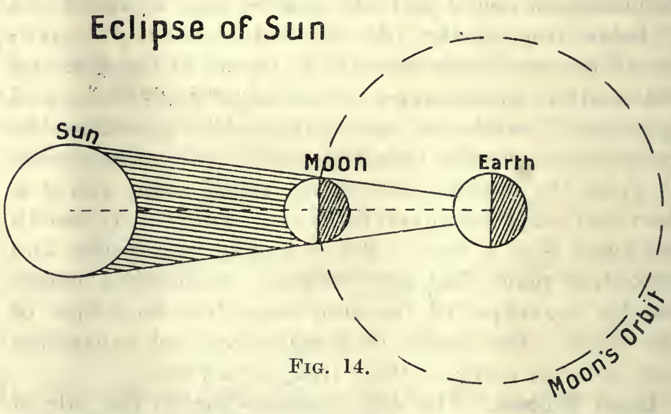

FIG. 14.

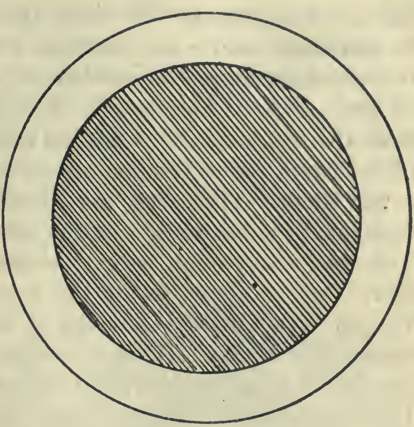

FIG. 15.

The breadth of the belt that it does cover varies according to the distance of the moon from the earth at the time. It never exceeds 180 miles.* The moon's orbit is slightly elliptical, so that her distance from the earth does vary slightly. (Her position at the nearest approach is called her **perigee**, her position at the farthest distance her **apogee**.) If the moon at a solar eclipse were in apogee, the lunar *umbra* would come to a point before it reached the earth, and so only the central portion of the sun would be eclipsed, leaving a ring of light around the moon's shadow (fig. 15). This form of eclipse is called the **annular** or ring eclipse. Of course, only those observers situated on a line with the centre of the shadow see the total and the annular eclipses. Observers outside the central line of the *umbra* belt see only a **partial** eclipse (fig. 16). It should be remembered that, since the earth's orbit round the sun is an ellipse, the sun as well as the moon is not always the same distance from the earth. When

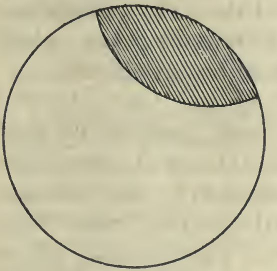

FIG. 16.

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* In 1905 the belt was 120 miles wide, in 1912 it was only half a mile.

the earth is nearest the sun, the earth is said to be in **perihelion,** and when farthest away, the earth is said to be in **aphelion.** The earth is in aphelion in June, and in perihelion in December. The difference of distance from the sun is about 3 million miles. In the early ages of the earth the difference was much greater.

The Earth.—The earth is a spherical body consisting of four different portions. In the interior is the practically unknown heavy mass, called the **centrosphere,** which forms more than nine-tenths of the total of the solid globe. Though very little is known of this centrosphere, two things are certain: (1) it is neither liquid nor incandescent, (2) it is the heaviest and densest portion of the earth. Its composition is entirely conjectural, it being supposed to be much the same as that of the meteorites (see p. 53) that fall upon the earth from outer space, viz. mainly nickel and iron. Though not actually liquid while confined within the interior, it quickly becomes so upon removal of the pressure of the overlying rocks. Around the centrosphere is a rocky crust of less than twenty miles in thickness called the **lithosphere.** Upon this lies the **hydrosphere,** which consists of all the waters of the earth, the oceans, seas, lakes, rivers, and the waters held within the porous substance of the rocky lithosphere. Above the hydrosphere and surrounding the whole earth is the envelope of gases called the **atmosphere.**

The Nebular Hypothesis.—Among the stars, beyond our solar system, are certain cloudy patches of light called nebŭlæ. Some, such as the one in the constellation of Orīon, are visible to the naked eye; but most can be detected only through a powerful telescope. Some have the appearance of irregular masses of glowing gas; others seem to consist of a cloud of solid particles definitely arranged as spiral arms springing from a central knot (*CK*, fig. 17).* The theory or supposition that our solar system originated from such a nebulous mass is called the **Nebular Hypothesis.** The arms springing from the central knot (fig. 17) show by their spiral formation that the whole nebulous mass is rotating about the knot. This knot is probably a sun in the process of formation, and, by a segregation of particles into knots in the arms, revolving and rotating planets may arise. According to this theory, our solar system in the beginning was such a nebulous mass of glowing gas, having its centre where the sun now is; extending far beyond the farthest limit of Neptune's orbit; and rotating in the same direction as our planets now rotate as they revolve round the sun. Cooling by the radiation of heat into space took place, just as the earth and the sun are now still losing

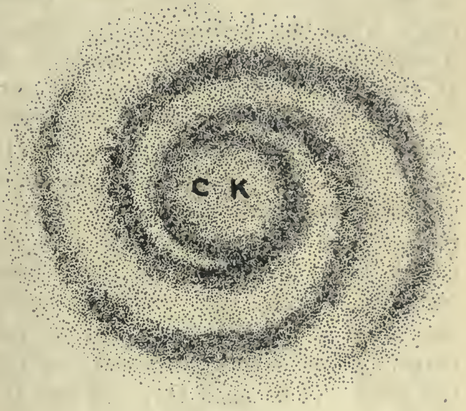

Fig. 17.

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* Spectrum analysis (see p. 21) of nebular light gives two different and distinct results, the continuous band and the isolated bright lines. The continuous band would seem to indicate that an apparent nebula is really a dense star-cluster: the isolated bright lines undoubtedly demonstrate the gaseous constitution of the true nebulæ. The latter gaseous nebulæ consist chiefly of nebulium (an unknown gas) and hydrogen.

Dr. V. M. Slipher, in May 1914, succeeded in obtaining photographs of nebular spectra (in Virgo) which show the nebula to be rotating.

heat. This cooling led to contraction, and in the course of time the parent mass threw off from its outer parts successive portions which continued to rotate and revolve in the original direction. Gravity gradually drew the mass of the detached portions together into spherical bodies, and these became planets. The sun is the remainder of the original glowing nebula, round which the various detached planets continue to revolve. Some of these planetary spheres have themselves thrown off rings, which by cooling, contraction, and concentration became spheres revolving round the parent planet, just as the moon revolves round our earth. In course of time the planetary masses of gas began to solidify. The first to reach the solid stage were: (1) the first portions detached, (2) the smallest portions detached from primary portions. Hence Neptune, the farthest distant of the planets, and our moon, a small secondary body, are both cooler than the earth. This hypothesis accounts for the intimate relation that exists between the planets and the sun; it also accounts for the internal heat of the earth. If the theory is correct, the time will come when the earth will be dead and cold like the moon, and when the sun will have lost all its heat.

Revolution of the Planets.—When a stone is thrown into the air, it does not rush off into space; it falls back again to the ground. The fact is, it is pulled back. Everything in, on, and over the surface of the earth is pulled down towards the centre by the attracting force of gravity (Chap. II). There is the same pull between the earth and the moon, between the sun and the earth and other planets, as there is between the earth and the thrown-up stone. This pull really acts both ways; the moon pulls the earth, and the earth also pulls the moon. It is the great difference in mass between the earth and the moon that gives to the earth the effective pull. The thrown-up stone pulls the earth, just as the earth also pulls the stone; but the pull of the stone is very insignificant compared with the pull of the earth.

When the planets were first detached from the contracting nebula, they were, so to speak, thrown off into space. This tendency to fly away from a central point is called **centrifugal** force. They would, indeed, have gone right off into space had they not been held in check by the force of gravity drawing them towards the central knot. Here comes in gravity, a **centripetal** force which compels bodies to fly towards, instead of away from, a common centre. When a horse-breaker is training a young colt, he makes the animal trot round him in a circle at the end of a rope. Why does the colt thus revolve around the man in a circular orbit? The colt would naturally like to get away, in fact is trying to do so all the time. This illustrates centrifugal force. He is restrained by the rope, which represents the centripetal force of gravity. Hence he *must* describe a circle. The same sort of reasoning explains why the moon revolves round the earth, and the earth and other planets round the sun.

Exercises

1. What different kinds of solar eclipses are possible, and how are the different kinds produced?
2. Why do eclipses of the sun occur so rarely, and why are those that do occur so frequently invisible at Greenwich?
3. Give some account of the "nebular hypothesis."
4. Explain why it is that sometimes one planet is visible in the sky and sometimes another. Are two planets ever visible in the sky at the same time?

5. Why is the sun sometimes red at rising and setting? Is a red sun ever seen in the zenith?
6. Why is there not a lunar eclipse every month?
7. Draw diagrams to show the appearance of any of the constellations with which you are acquainted; give their names, and state in each case the seasons of the year in which they may be seen in England.
8. How are eclipses of the sun caused, and why do they occur so rarely? Describe the appearance of an eclipse of the sun as seen by an observer on the earth. (Camb. Sen. Loc.)
9. It was "full moon" on March 10; on what date will the next "new moon" occur? At what hour did the "full moon" rise on March 10, and at what hour did it set? Is the time of the rising and of the setting of the "full moon" the same for all seasons of the year? If not, state the differences.
10. Explain and illustrate by a diagram (*a*) the phases of the moon, (*b*) the succession of the seasons, (*c*) the variation in the lengths of day and night.
11. If the moon rises at 6 p.m. to-day, about what time will it rise to-morrow? How can you tell whether a half moon is at its first or its last quarter?
12. What is meant by the terms "horizontal plane," "oblique plane," and "vertical plane"?

CHAPTER VII

Rotation, Revolution, and the Seasons

Rotation.—Every day over most of the earth the sun appears to rise in the eastern sky and, after travelling across the heavens, to set in the west. It was at one time believed that the earth was a stationary body, and that the sun revolved round the earth once every twenty-four hours. Not only the sun, however, but all the heavenly bodies, sun, moon, and stars, were believed to be concerned in this revolution. Indeed, this apparent movement of the whole heavens round the earth may be, and has been, photographed, by pointing the camera at the Pole Star (the point around which the revolution seems to take place). On a fine, starry night expose a plate for two hours or more with the camera pointing to the Pole Star. When you develop the plate you will find the stars are photographed not as dots of light but as arcs of circles greater or less according to the time of exposure. Now, either the heavens are really revolving round the earth from east to west or the earth is rotating the other way. But the former cannot be the case, for if it were, the stars are so very far distant from us that the nearest of them would have to move at the rate of five million million miles an hour to get round the earth once in twenty-four hours. Moreover, telescopic observations show that the sun, the moon, and all the other planets rotate round an axis which is always the shortest diameter, so that (arguing by analogy) we may fairly conclude that the earth must be doing what the others are doing. Many experiments have been performed which prove the truth of the earth-rotation theory, the chief and most convincing of which are known as (1) the pendulum experiment and (2) the falling ball experiment.

(1) **The Pendulum Experiment.**—This was first done by Jean Bernard Foucault, an eminent French scientist, in 1851. But the same experiment may be performed by anybody. Form a pendulum by attaching a heavy ball to one end of a long wire, and fastening the other end of the wire to a ring which is then hung upon a hook in the ceiling of the class-room. Underneath the pendulum as it hangs vertically from the ceiling place a table. To start the pendulum swinging steadily, tie the weight with thread to the wall and, when ready for the experiment, burn the thread. Face the pendulum as it swings so that it swings straight at you, and lay a long, flat rod on the table exactly in a line with the swing. Now, a pendulum once set swinging has no power to change the direction of its swing, whatever may happen to the beam or ceiling from which it is suspended. But you will soon find that the swing leaves the flat rod and begins to make an angle with it. In half an hour the angle will be about 8°. Therefore it must be the table that is moving, and therefore also the earth is moving. By dividing the number of degrees moved through into the number of minutes taken, you will find that the pendulum changes its plane of swing at the rate of about 1° in 5 minutes. And this, if continued, would mean a complete rotation of the table in about twenty-four hours. To show that it is the earth that is rotating and not the

pendulum changing the plane of its swing, take a teacup or a tumbler of water, and carefully place a wooden match upon the surface of the water. Turn the cup round once without shaking the water, and it will be seen that the match does not change its original direction. Hence the rotation of the table made the pendulum appear to change its swing. To show that the rotation of the table means the rotation of the earth, take a globe and over the British Isles paste a slip of paper marked with an arrow pointing to the north pole. This piece of paper may be taken to represent a huge table standing on the British Isles. Now rotate the globe slowly. Notice that the arrow at starting pointed to one wall of the room, and that when the globe has made half a rotation, the arrow is pointing to the other side of the room. At the end of a complete rotation the arrow points again in the original direction. Hence we see that the rotation of the earth means the rotation of the table that stands upon it, and vice versa.

(2) **The Falling Ball Experiment.**—It has been found that things dropped down a pit shaft do not directly reach the bottom but lodge somewhere against the eastern side. The explanation is that by the rotation of the earth all things at the surface have an eastward velocity of a thousand or more feet per second, while nearer the centre the velocity becomes proportionally less, and at the centre nil. The falling body, as it falls, continues its eastward movement with the rotating earth, and not only keeps its original velocity, but increases it by gravity. The walls and timbers in the depths of the shaft are travelling more and more slowly eastward than the falling body, and therefore the falling body overtakes the side of the shaft that is east of it. The same effect may be seen by throwing a ball outwards from the western side of a

sufficiently high tower. The rotation of the earth is the only feasible explanation of this phenomenon.

Day and Night.—As the earth rotates before the sun, one side receives the sun's light, the other being in outer darkness. The part of the sphere illuminated is having day, the other part is having night. Only one side of the earth can be turned towards the sun at once, but the rotation of the earth brings all parts in succession into the sunlight. The vertical line down the middle of the illuminated hemisphere is the mid-day line, and all places on that line have their noon at the same moment. The period of rotation has been divided into twenty-four equal parts called hours, so that the definition of an hour is the twenty-fourth part of the time taken by the earth to rotate once on its axis.

Revolution.—So far, the revolution of the earth round the sun has been taken for granted. Let us now try a simple experiment to illustrate a method of proving it. Arrange a class of boys in a circle, *A*, *B*, *C*, etc., with two boys *O* and *P* inside. *O* remains stationary in the middle of the ring, *P* walks round *O* (fig. 18). As *P*, who represents the earth, walks round *O*, who represents the sun, let him call out in turn the names of the boys *A*, *B*, *C*, etc., in line with whom he sees *O* as he moves from P_1 to P_2 to P_3, etc. All must see at once that if *P* at P_1 sees *O* in front of *A*, at P_2, *O* in front of *B*, at P_3, *O* in front of *C*, he must be walking

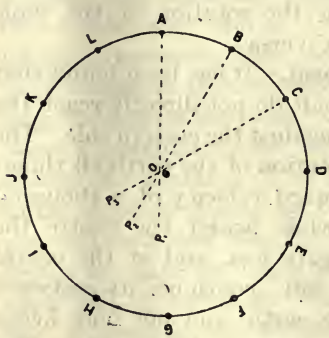

FIG. 18.

round *O*. The experiment shows why the sun, observed from the earth, appears to move in a circle in the heavens among the groups of stars.

The Zodiac and the Year.—The stars of the sky have from the earliest times been divided into groups called *constellations*, which have received names from fancy or fable according to their supposed resemblance to certain persons, animals, or things. The constellations of the northern hemisphere are quite distinct from those of the southern. Between these and lying along the outer edge of the extended plane of the ecliptic is a ring of twelve constellations known as the **zodiac.** It is through these zodiacal constellations that the sun observed from the earth appears to move. By following this apparent path of the sun through these constellations or **signs of the zodiac,** astronomers are able to tell exactly where one year ends and another begins. The constellations in their proper order appear in the following rime:

"The Ram, the Bull, the Heavenly Twins,
And next the Crab the Lion shines,
The Virgin and the Scales,
The Scorpion, Archer, and He-Goat,
The Man that bears the watering-pot,
The Fish with glittering tails."

The sun enters the Ram on March 21, and takes about a month to move through each constellation. Unfortunately, however, the sun does not take an even number of solar or rotation days to complete his round. In 365 days he has not arrived quite at his starting-point, and it takes about 6 hours extra to finish the course. We therefore finish our year at the end of 365 days and ignore the extra hours. At the end of another year we have a further 6 hours; at the end of 4 years, nearly 24 extra hours. So we make every fourth year contain

366 days and call it **leap year.** The 24 hours every 4 years is really a trifle too much, and to correct this we omit the extra day whenever the leap year falls in the first year of a century whose first two digits are not exactly divisible by 4 (*e.g.*, 1700, 1800, 1900).

Now, either the sun does move eastwards (as seen from the earth) among the stars, or the earth moves round the sun westwards. Transits of Venus and Mercury (see p. 52) indicate the revolution of these planets round the sun. By analogy, therefore, we may conclude that the earth also revolves round the sun.

Parallax.—On a portion of railway line from *A* to *B* (fig. 19) let a trolley travel backwards and forwards. On the trolley let there be fixed a telescope capable of rotary movement in a horizontal plane. At *A* in order to sight the tower the telescope must be turned in the direction

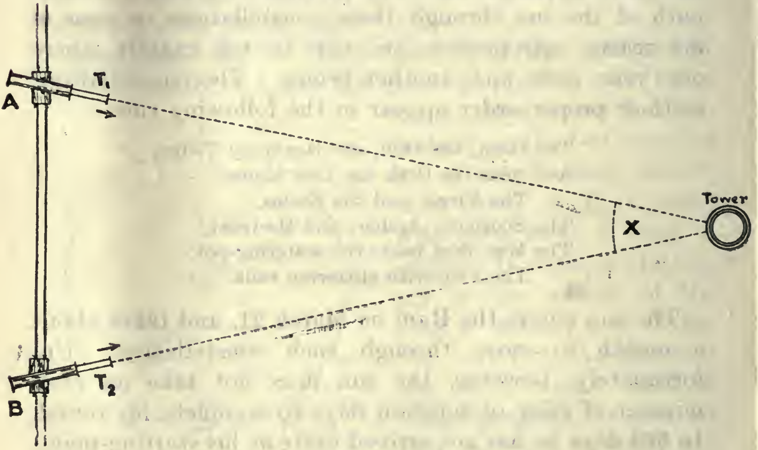

FIG. 19.

T_1, at B it must be in the direction T_2. To the observer on the trolley as he moves from A to B or from B to A the tower will seem to shift its position, because it is necessary to shift the position of the telescope. It will be noticed that the angle through which the telescope moves is equal to the angle X formed by the converging lines of direction at the tower. This apparent displacement measured by the angle is called the **parallax** of the tower. If we know the tower to be a fixture, the angle of parallax is proof of the movement of the telescope either from A to B or from B to A.

Parallax as a Proof of Revolution.—In place of the fixed tower, astronomers make use of some fixed star. Two quite distinct angles may be measured for parallax. The angle subtended by the earth's diameter at a point in the heavens is the *diurnal* parallax of that point; the angle subtended by the diameter of the earth's orbit is the *annual* parallax. Observations of a star made at opposite ends of a diameter of the earth show no diurnal parallax, so vastly distant are the stars from the earth. Even the sun shows no greater diurnal parallax than 8″. But if a star * be observed at a certain date, and again six months later, it is found to suffer displacement or parallax (annual). From the first observation the star continues to move until the maximum displacement has occurred six months later, and then it appears to move back to its former position, which it reaches twelve months after the first observation. From the diagram (fig. 20) it will be seen that this is not only a proof that the earth revolves round the sun, but also verifies the time taken. For it is quite clear that the earth moves from E_1 to E_2 in the six months, and it must either move in a straight line or along a curve. But if it moved along a straight line it would have to pass either right through the sun, or at least quite close thereto. We know that this does not happen. We know that the earth is never more than 3,000,000 miles nearer to the sun at one time than at another, *i.e.* $\frac{1}{30}$ of the radius of its orbit. And so the conclusion is that the earth moves from E_1 to E_2 and back again along a closed curve.

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* Comparatively few stars are sufficiently near the earth to have even an annual parallax. The distances of stars are estimated in "light-years," a light-year being the distance traversed by a sidereal ray of light in a year at the rate of 180,000 miles per second.

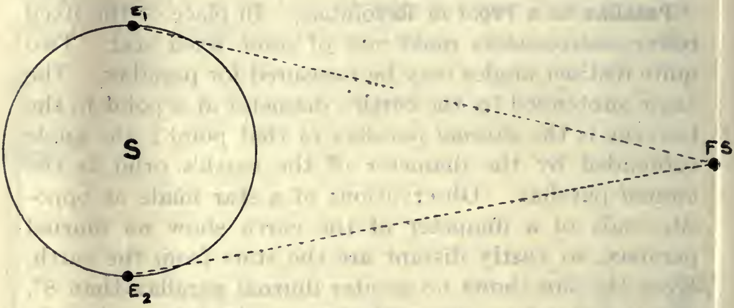

FIG. 20.
(*FS* = Fixed Star)

The Seasons and the Effect of Axis-tilt.—In a round, flat board bore sockets at an angle of $23\frac{1}{2}°$ from the vertical in the positions marked 1, 2, 3, 4 (fig. 21). At *S* in the centre of the board bore a vertical candle-socket. A lighted candle placed in this socket will represent the sun; a ball painted white with a pin thrust through, as at *B*, will represent the earth, and by moving this ball from socket to socket through 1, 2, 3, and 4, the four chief positions of the earth in its orbit may be shown. The experiment should always take place in a semi-

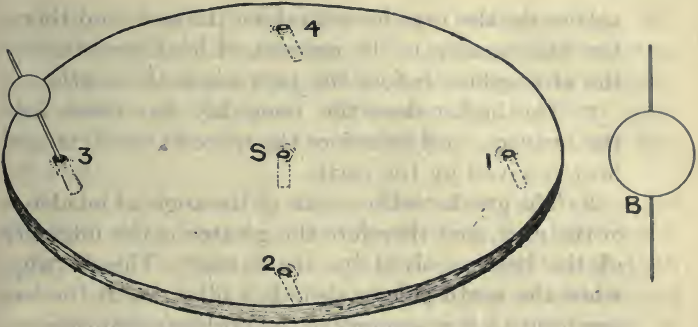

FIG. 21.

darkened room, so that the candle-light may be more effective. You must notice in moving the earth through the four points of its orbit, that because of the tilt of the axis, the north pole at 1 is pointing towards the sun, and at 3 away from the sun. Position 1 allows:

1. The north polar regions to be wholly within the hemisphere of light, and the south polar regions to be wholly within the hemisphere of darkness.
2. The rays of the sun to fall more vertically in the northern hemisphere, and more obliquely in the southern.
3. The days to be longer than the nights in the northern hemisphere, and the nights to be longer than the days in the southern.

Position 3 allows the same things to be true of the corresponding regions on the other side of the equator. Now, the more vertically the sun shines upon the earth (fig. 22)—

1. The less atmo-

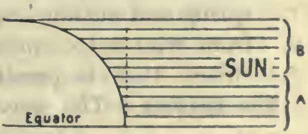

FIG. 22.

sphere do the rays have to shine through, and therefore the smaller is the amount of heat absorbed by the atmosphere before the rays reach the earth.

2. The higher does the noon-day sun climb into the heavens, and therefore the more is the light and heat received by the earth.

3. The greater is the cosine of the angle of incidence of the rays, and therefore the greater is the intensity of the heat received by the earth.* This is why, when the north pole is at its full tilt towards the sun (position 1), it is summer in the northern hemisphere; and why, since at the same time the south pole is at its full tilt away from the sun, it is winter in the southern hemisphere. When we move the model earth from position 1 to position 3, *i.e.* to the opposite point of its orbit, we notice that the poles have changed their position with respect to the sun. The north pole is now turned away from the sun and is pointing into space; while the south pole is pointing towards the sun. What was true of the northern hemisphere in position 1 is now true of the southern and vice versa. The whole revolution round the sun takes twelve months. Therefore six months after the northern midsummer day and southern midwinter day come the southern midsummer day and northern midwinter day. Midway between these two positions, *i.e.* at positions 2 and 4, on opposite sides of the orbit, are the intermediate seasons of spring and autumn, spring to the hemisphere passing from winter to summer, and autumn to the hemisphere that is passing from summer to winter.

The Seasons.—The seasons *commence* at the solstices and equinoxes. By common usage, however, June 21, which is really the beginning of the astronomical summer, is called midsummer day, probably because it falls about the middle of the year. December 22 is called midwinter day, whereas astronomically it is the *first* day of winter.

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* The law of illumination is that "illumination is proportional to the cosine of the angle of incidence."

At the equinoxes (fig. 21, positions 2 and 4) we see that the light-dark line, *i.e.* the line dividing the light hemisphere from the dark, lies along a circle passing through both poles. (This is not easily seen except in a semi-darkened room.) This means that at the equinoxes every place on the earth gets twelve hours day and twelve hours night at one rotation. This equality, however, does not continue; for as soon as the earth has passed these points in its orbit; the inequality of day and night recommences. The changing of the seasons, then, is due, not alone to the revolution of the earth round the sun, but to the revolution combined with the slope of the earth's axis. The least variation between hot and cold seasons occurs within the tropics, the greatest amount in regions beyond the tropics. Within the tropics the variations are not between a summer and a winter, but (usually) between a wet and a dry season. If the axis were upright, the only change in season anywhere on the earth would be the change caused by the earth being farther from the sun in one part of its orbit than in another. This difference does exist; for the sun is in aphelion on July 1, and in perihelion on January 1. The inclination of the axis more than makes up for the farther distance of the earth when our pole is tilted towards the sun, and so we get our summer in aphelion. But the southern hemisphere will get its summer in perihelion. What difference does this make to the southern summers?

To sum up.—**Rotation** causes the apparent risings and settings of the sun each day, and thus causes day and night. **Revolution** alone causes the sun to appear to move eastwards among the fixed stars, and the annual parallax of certain fixed stars; revolution *plus* the **inclination of the earth's axis** causes different lengths of day and night, and the succession of the seasons through the year.

EXERCISES

1. Why is it colder in winter than in summer?
2. Describe fully an experiment by which the rotation of the earth can be demonstrated.
3. Give an account of the variations in the length of a day experienced at the north pole, London, and the equator, throughout one year. Draw diagrams illustrating the apparent path of the sun during midsummer day at each of these places.
4. Give an account of the apparent movement of the stars depending upon—(*a*) the earth's rotation on its axis, (*b*) the earth's revolution round the sun.
5. "Rotation gives day and night; revolution gives the seasons." Show that this statement does not contain the whole truth.
6. Explain why in our islands there are long nights and short days in the winter months, but short nights and long days in the summer. When are the hours of daylight and of darkness equal in number?
7. Point out how the movements of the earth enable us to measure days, seasons, and years. Show how the length of daylight varies at the Arctic Circle in the course of a year. (Oxf. and Camb. Lower Cert.)
8. Explain as clearly as you can how the apparent height of the noonday sun above the southern

horizon at Greenwich is affected by the motion of the earth in its orbit. (Oxf. and Camb. Sch. Cert.)

9. State clearly the meaning of the following terms: ecliptic, equinox, and equator. Show how the plane of the earth's orbit is related to the position of the poles and point out the effects upon the seasons. (Oxf. and Camb. Sch. Cert.)
10. At what times of the year does the sun rise exactly in the east and set exactly in the west? Give reasons for your answer. (Oxf. Jun. Loc.)
11. State how the motion of a body on the earth's surface is affected by the earth's rotation on its axis (Ferrel's law), and discuss examples of the application of this law to geographical phenomena. (Oxf. Sen. Loc.) (See pp. 149 and 277.)
12. Explain why in June all places north of the equator have a longer day than night, while all places south of the equator have a longer night than day.

    In what direction would the sun cast a shadow of an upright stick at noon in (*a*) June and (*b*) December at a place in 5° N. latitude? Give reasons for your answer. (Oxf. Jun. Loc.)
13. Explain why it is winter in England when it is summer at the Cape of Good Hope.

    At what periods of the year are the days and nights of equal length all over the earth? Give reasons for your answer. (Oxf. Jun. Loc.)
14. Explain why a point on the earth's surface moves more slowly in high latitudes than in low ones.

    How does this fact affect the directions of certain currents in the air and in the ocean? Give examples. (Oxf. Jun. Loc.)
15. Give a rough comparison of the lengths of the day

(*i.e.* the number of hours the sun is above the horizon) on December 22 and June 21 at the following places: (*a*) Aberdeen (latitude 57° N.); (*b*) Dunedin (latitude 46° S.). Account for the differences observed. (Oxf. Sen. Loc.)

16. Explain each of the following: (*a*) How day becomes night; (*b*) how winter becomes summer; (*c*) how two places on the same meridian may have different times at the same moment. (College of Preceptors.)

CHAPTER VIII

Latitude

Determination of Latitude.—Distance is always measured on the earth's surface in degrees, and therefore the latitude, or the distance of a place north or south of the equator, is always reckoned in this way. To determine one's latitude it will be found necessary to have some instrument which will measure the angular distance of the sun above the visible horizon. For this purpose a **sextant** is generally employed. There are several modified forms of the sextant suitable for school work. Among these is the Anglemeter,* which has only one reflector. With it readings may be taken to one de-

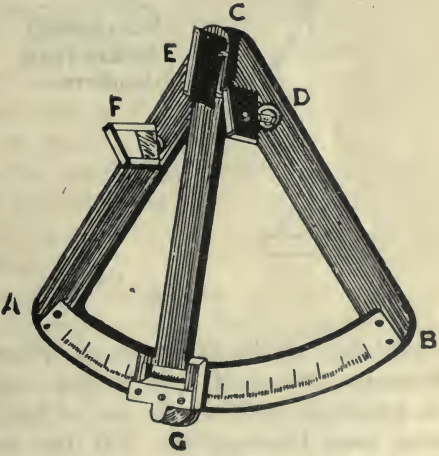

FIG. 23.

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* The Anglemeter is manufactured and sold by Messrs. W. & J. George, Ltd., Great Charles Street, Birmingham.

gree. For those who want to obtain more accurate observations, a more expensive instrument fitted with two mirrors may be obtained (see fig. 23). This consists of a rotary arm, *EG*, free to move about the sector *ABC*, which is graduated in degrees from 0° to 130°. A vernier scale is attached to the rotary arm at *G*, by which readings to a minute * may be recorded. To use this instrument some

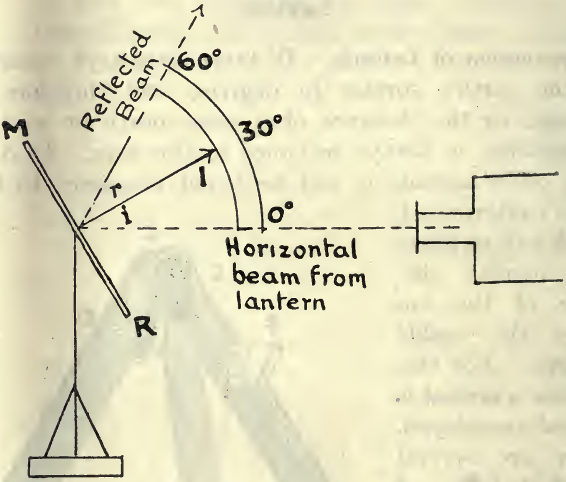

FIG. 24.

knowledge of the principles of optics is required. If a horizontal beam of light is cast upon a mirror resting in a vertical position, the ray of light will be seen to be sent back horizontally. Tilt the mirror until the indicator *I* (fig. 24) has rotated through 30°, as shown in the diagram, and the beam will now be seen to be reflected along 60° on the graduated arc. It is clear that the angle i which the indicator makes with the horizontal beam—known as the incident ray—is equal to the angle r which the indicator makes with the reflected ray. To state this in other words, *the angle of incidence is equal to the angle of reflection.* Knowing this law of light, it is easy for the observer to understand the principle on which the sextant is constructed.

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* *I.e.* of a degree.

How to use the Sextant.—The sextant may be used to determine heights and distances in the same way as that described for the theodolite (see p. 545), but its primary use is to assist in the determination of latitude. To measure any angle of elevation, say, that subtended at the place of observation by the top and bottom of a poplar tree, you first look through the pin-hole at *D* (fig. 23) until the base of the tree appears through the plain glass in the top half of *F*, holding the sextant in a vertical position during the observation. Then move the rotary arm until the top of the tree is reflected in the silvered mirror at the bottom half of *F*, and is seen in a direct line with the base of the tree as observed through the plain glass. Clamp the arm by means of the screw at *G*, when you have thus sighted the objects, and read off the angle which the rotary arm measures on the scale, using the vernier scale attached.

To determine the angle subtended by two objects in the same horizontal plane, the sextant must be held in a horizontal position. Sight one of the objects through the plain glass at *F* and rotate the rotary arm till the other object is reflected on a level with it in the silvered half of the same glass. The angle recorded by the rotary arm is that subtended at the place of observation by the two objects.

To read the angle measured by aid of the vernier, first look along the vernier until you find one of the marks along it to coincide with another division on the arc of the sector. If the vernier reads to a tenth of a degree on the arc of the sector, then the angle observed is that marked on the arc of the sector plus $\frac{1}{10}$th of a degree. If the second vernier division coincides with a division on the arc of the sector, then the angle is that marked on the arc plus $\frac{2}{10}$ths of a degree, and so on for all the divisions on the vernier.

With an artificial horizon (see p. 87) the altitude of the Pole Star at night, and the sun at mid-day, may be measured. Knowing these angles, the latitude of any place may be found by applying the rules proved later on in this chapter.

Determination of Latitude at the Equinoxes.—At the equinoxes (March 21, September 23) the sun's position at noon is directly over the equator. To an observer standing on the equator (latitude zero) the sun would appear in his *zenith*, that is directly overhead, and the angle of its elevation above the horizon would therefore be 90°. To an observer at either pole (latitude 90°) the sun would appear on the same date low down on the horizon, and its altitude would be zero. Reasoning in the same way, an observer in latitude 89° would see the sun at noon 1° above the horizon. From this it is clear, that if the sun's altitude at noon above the horizon for any place be known and subtracted from 90°, the latitude of the place will have been thus obtained. We may easily adduce a geometrical proof of this rule, but before doing so we must have a clear idea of certain geographical terms. In the diagram (fig. 25) if W represents our position on the earth's surface, then the point Z is termed our **zenith**, and ZW on being produced through the earth's centre (O) points towards our **nadir**. The tangent SV represents our horizon, that is, the plane through the place parallel to the surface of standing water, or perpendicular to a plumb line. The latitude of *W* is the number of degrees in the arc *WT* = the angle *WOT*. The sun's altitude is shown by the angle the line drawn in its direction makes with *WV*, and the angular distance between the sun and the zenith is called **zenith distance.**

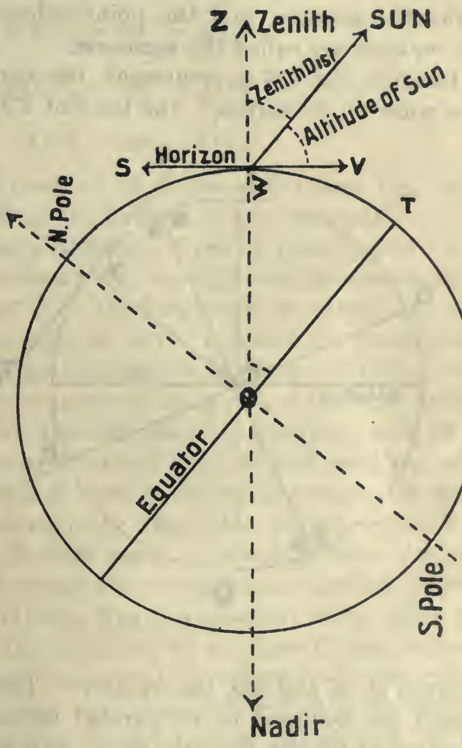

FIG. 25.

The path that the earth follows in its course in the heavens during the year is called its **orbit,** and the plane in which the earth's orbit lies cuts the plane of the equator at an angle of 23½°. This plane is called the plane of the **ecliptic.** Because the plane of the ecliptic does not coincide with the equator, the inclination of the earth's axis towards the sun changes from time to time during the year, so that the sun appears to move some distance north and south of the equator. The points on the ecliptic where the sun seems to make his turn and come back towards the equator are called the **solstices**, and the points where the sun crosses the equator are called the **equinoxes.**

Imagine Fig. 26 to represent the earth, and that X is a point on its surface; the tangent TT_1 represents the horizon at X and QQ_1 the equator. The lines XS^1, Q_1S, which are assumed to be parallel because of the great distance of the sun from the earth, represent the direction of the sun as seen from X and Q respectively at the equinoxes. Now, since XS^1 is parallel to Q_1S or OS, and OX intersects them, the angle $ZXS^1 =$ the angle XOS, that is the zenith distance of the sun equals the latitude of X. We cannot in practice take an observation of our

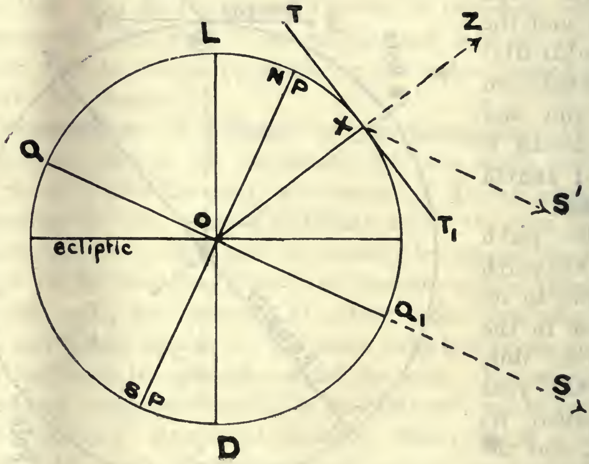

FIG. 26.

zenith with the sextant, seeing that there is no object directly overhead which we can with any definiteness locate. But we can, however, measure the sun's altitude above the horizon, that is the angle S^1XT_1. In the figure;

$$\widehat{S^1XT_1} = 90^\circ - \widehat{ZXS^1}$$

$$\widehat{S^1XT_1} = 90^\circ - \widehat{XOS}$$

$$\therefore\ \widehat{XOS} = 90^\circ - \widehat{S^1XT_1}$$

That is, the latitude of X equals 90° minus the sun's noon altitude above the horizon at the equinoxes.

To find the Sun's Altitude.—Even in open country it is often difficult to obtain the sun's altitude by observations with the sextant when the horizon is obscured. In such cases it is necessary to have recourse to an artificial horizon, which may be made by pouring a little mercury or black ink into a saucer so as to reflect the sun's image. To find the sun's altitude above the horizon, first of all hold the sextant in a vertical position and sight the sun's image in the liquid until it is seen through the plain glass of the instrument. For this purpose it will be necessary to walk backwards or forwards from the artificial horizon, keeping the sextant in a vertical position all the time. Having found a position from which the sun's image in the liquid can be so viewed, then, without altering your position, move the rotary arm of the sextant until the sun's image also appears reflected in the silvered glass of the sextant. By careful adjustment of the instrument the two images of the sun may be brought into line in the mirror F (fig. 23). The angle which the rotary arm then indicates is equal to twice the altitude of the sun above the horizon, and must therefore be halved to obtain the true angle (see fig. 27). In the diagram the angle SXZ = the angle YXZ. Therefore the angle SXZ equals half the angle SXY. On the sextant described on pp. 81–4, however, the graduations are already marked as double the angle between the mirrors, so that if the arm is turned from the 0° position through 30°, it will be found that the reading on the scale is 60°.

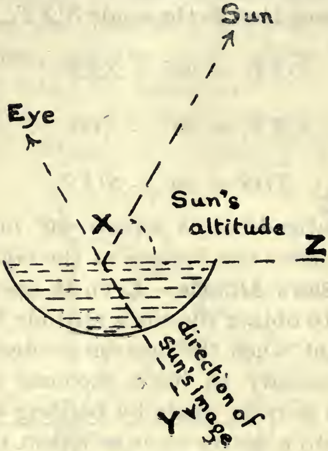

Fig. 27.

Caution.—It is dangerous to look at the sun with the naked eye. A small piece of coloured glass should always be placed over the pin-hole or sight when taking observations.

Latitude at the Solstices.—This will differ according as the sun is (*a*) north or (*b*) south of the equator.

(*a*) At the summer solstice the sun's declination or its distance north of the equator is 23½°. Its direction as seen from X and P (fig. 28) will be represented by the lines XS^1 and PS respectively. These lines are assumed to be parallel because of the great distance of the sun from the earth.

The latitude of $X = \widehat{XOQ_1}$ (fig. 28)

$= \widehat{POQ_1} + \widehat{XOP}$

$= \widehat{POQ_1} + \widehat{ZXS^1}$ (since XS^1 is parallel to OS, and OZ intersects them).

Also $\widehat{S^1XT_1} = 90° - \widehat{ZXS^1}$

$\therefore \widehat{ZXS^1} = 90° - \widehat{S^1XT_1}$

The latitude of $X = 90° - \widehat{S^1XT_1} + \widehat{POQ_1}$

Hence the latitude of X at the *summer* solstice equals 90° *minus* the sun's altitude *plus* the sun's declination. This rule holds good for any day in summer, and the

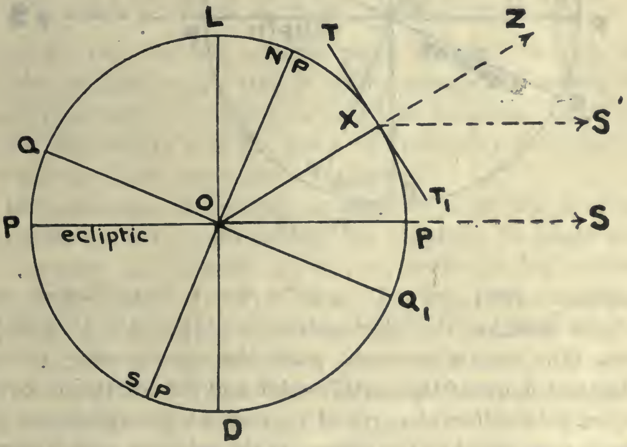

FIG. 28.

sun's declination may be found by consulting "Whitaker's Almanack." If such an almanack is not available, a very near approximation can be arrived at by assuming that there is a change of declination of $23\frac{1}{2}°$ in about 91 days, *i.e.*, the change per day $= \frac{23\frac{1}{2}}{91} = \frac{47}{182} =$ very nearly $\frac{1}{4}°$. For example, the declination 2 days after the summer solstice $= (23\frac{1}{2} - 2 \times \frac{1}{4}) = 23°$; for 4 days before the winter solstice the declination $= (23\frac{1}{2} - 4 \times \frac{1}{4}) = 22\frac{1}{2}°$. This fails as an accurate guide because (owing to the elliptical shape of the earth's orbit and the earth's unequal velocity in different parts of its course) the difference per day is very slight as the sun nears the solstices, and is correspondingly greater near the equator.

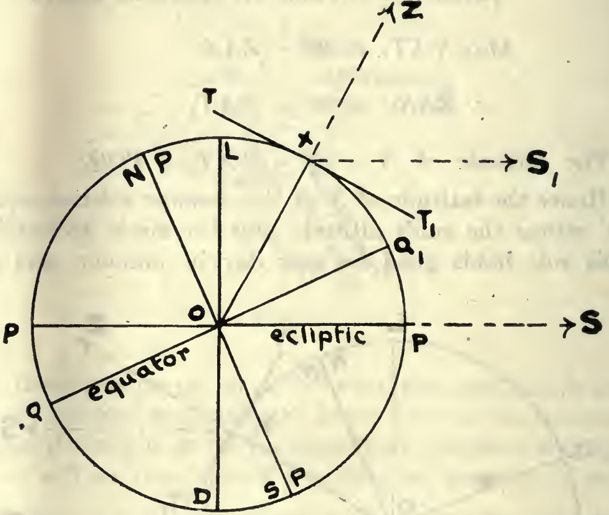

FIG. 29.

(*b*) In the second case, when the sun is *south* of the equator (winter), the earth's axis should be drawn with the north pole inclined away from the sun, as in fig. 29. As in the previous case, the direction of the sun will be represented by the parallels XS_1, PS, but the sun's declination is now 23½° south of the equator. Since XO cuts the parallels XS_1, OS,

$$\begin{aligned}\widehat{ZXS_1} &= \widehat{XOS}\\ &= \widehat{XOQ_1} + \widehat{Q_1OP}\end{aligned}$$

$$\text{Now the latitude of } X = \widehat{XOQ_1}$$

$$\therefore \text{ the latitude of } X = \widehat{ZXS_1} - \widehat{Q_1OP}$$

$$\text{also } \widehat{ZXS_1} = 90° - \widehat{S_1XT_1}$$

$$\therefore \text{ the latitude of } X = 90° - \widehat{S_1XT_1} - Q_1OP$$

That is, the latitude of any place at the time of the winter solstice or any day in winter equals 90° *minus* the sun's noon altitude *minus* the sun's declination. Both the sun's declination and the sun's altitude may be obtained by the methods previously explained.

Determination of Latitude at Night.—(i) As the mariner depends upon the sun during the daytime to assist him in locating his position at sea, so he looks for another heavenly body—the Pole Star—to help him in determining his latitude during the night. The Pole Star is always almost directly over the north pole. It may be assumed that an observer in the northern hemisphere would observe the Pole Star in a direction parallel to the earth's axis, its distance from the earth being very great. In fig. 30 its direction at X is shown by the line XS_1,

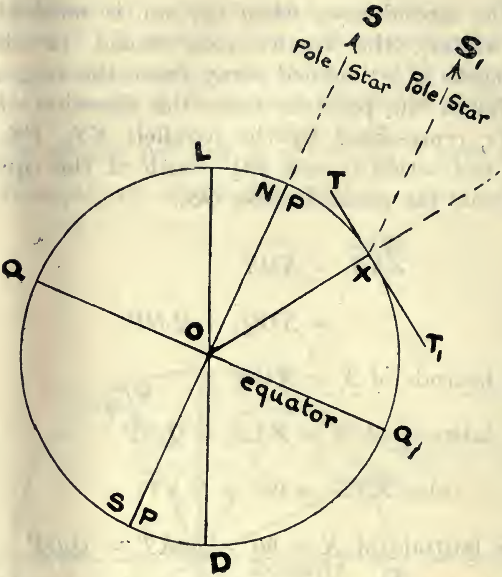

FIG. 30.

and since the angle TXS_1 represents the Pole Star's altitude above the horizon, the angle S_1XZ represents its zenith distance.

$$\text{Now the latitude of } X = \widehat{XOQ_1}$$
$$= 90^\circ - \widehat{SOX}$$
$$\text{But } \widehat{SOX} = \widehat{S_1XZ}. \quad (\text{since } OX \text{ intersects the parallels } OS \text{ and } XS_1.)$$
$$\therefore \text{ the latitude of } X = 90^\circ - \widehat{S_1XZ}$$
$$= \widehat{S_1XT} = \text{the Pole Star's altitude above horizon.}$$

Hence the latitude of X is equal to the altitude of the Pole Star above the horizon. This angle may be determined with the sextant in the same way as that described in taking observations of the sun.

(ii) If it be desired, the latitude of any place may be found equally well by taking observations of any star * with the sextant. In fig. 31 let X represent a place in any latitude, Z the zenith of the place, and the parallels XS_1, OS the direction of the star as seen at X and O respectively.

$$\text{Then the latitude of } X = \widehat{XOQ_1}$$
$$= \widehat{XOS} + \widehat{SOQ_1}$$
$$= \widehat{ZXS_1} + \widehat{SOQ_1}$$

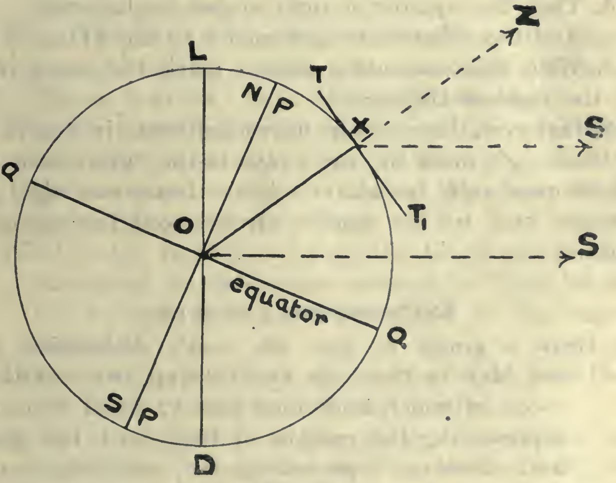

Fig. 31.

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* Provided the star chosen is on the meridian.

Therefore the latitude of X is equal to the zenith distance of the star *plus* the star's declination. The zenith distance may be obtained with the sextant by observing the star's altitude above the horizon and subtracting it from 90°. The declination of the star may be obtained by consulting "Whitaker's Almanack," in which the declination is given to the fraction of a second.

Latitude Diagrams.—It is well to have some definite method for drawing latitude diagrams in order to prevent confusion. The following suggestions obviate possible errors.

1. First draw *LD* (see figs. 28–31), the *light-dark* line vertically through the centre of the circle.

2. Then draw the axis either thus— ╲ for the northern winter solstice, or thus— ╱ for the northern summer solstice, but making an angle of 23½° with *LD*.

3. Then the equator at right angles to the axis,
And the ecliptic at right angles to the *LD*.

4. With *this convention* always mark the sun's rays on the *right* of the circle.

5. However, if the axis be drawn indifferently thus— ╲ or thus— ╱, mark the sun's rays in the former case *left* for summer, *right* for winter; in the latter case *right* for summer and *left* for winter, always counting northern seasons.

Exercises on Latitude

1. Draw a graph to give the sun's declination for any day in the year by choosing two ordinates —one of which is divided into 12 equal divisions representing the months of the year; the other into divisions representing the sun's maximum distance above and below the equator. To draw the curve the sun's declination for the first day

of each month may be obtained from "Whitaker's Almanack."

2. The altitude of the sun at noon in summer is found with the sextant to be 55·85°, and the declination 24·56° (from "Whitaker's Almanack"). Find the latitude of the place.
3. Use the school sextant and an artificial horizon to determine your latitude. Compare your result with that given on the map.
4. Draw two diagrams, one showing the sun's altitude and zenith distance for latitude 50° N. at the summer solstice, the other showing the same thing for the same latitude at the autumnal equinox. From this, knowing the number of days from the summer solstice to the autumnal equinox, calculate the angular declination of the sun per day.
5. When the sun is directly overhead at any place (*i.e.* altitude 90°), what part of a circle's circumference does its visible daily path trace out ?
6. Find the altitude of the sun at midday for the following places at the time of the winter and of the summer solstices—London, Aberdeen, Melbourne, Calcutta, New York.
7. What is the relation between the height above the horizon of the midsummer sun and the depth below the horizon of the midwinter sun at the same latitude ?
8. Draw a diagram to show that rays of light from the sun to the earth are virtually parallel.
9. If the circumference of the earth is reckoned as 25,000 miles, what is the length in miles of a degree of latitude ? State the reason for the slight variation in the length of a degree of latitude.

10. Where are the Tropic of Cancer and the Arctic Circle? What do they indicate?
11. What difference would be made to the climate of London if the earth's axis were inclined to the ecliptic at an angle of 45° instead of 66½°?
12. What deductions can be made from observing throughout the year the positions and lengths of the shadow (cast by the sun) of a vertical stick placed on a horizontal stand?

EXERCISES ON THE USE OF THE SEXTANT

13. Draw a plan of your playground by means of the sextant and a chain, and thence calculate its area.

    [Angles formed by the boundaries of the playground should be measured by the sextant at each corner, and the lengths of the boundary fences chained.]
14. Choose a convenient base-line and determine the distance between two inaccessible objects visible at its extremities by aid of the sextant.

    [Drawing to scale or using trigonometrical formulæ may be employed.]
15. Find the latitude of your school (*a*) at night by observation of the Pole Star, (*b*) during the day by observation of the sun at twelve o'clock. In the latter case use an artificial horizon.
16. Determine the height of your school buildings by choosing a base-line drawn at right angles to the school wall, and finding the angles of elevation of the top of the school as seen at both ends of the line.

CHAPTER IX

Longitude and Time

Determination of Longitude.—The longitude of a place is the angle between the plane of its meridian and that of the meridian of Greenwich. It is measured by the angle subtended at the centre of the earth by the arc cut off by these planes on the equator. We are enabled to calculate this distance at any place on the earth's surface because of the relation existing between time and longitude. Time is reckoned by observing the sun. For example, when the sun appears directly over any meridian, it is noon at all places situated on that meridian. In other words, every place may take its time from the appearance of the sun over its meridian. Time thus calculated is styled **local time.** We know that the earth rotates on its axis once every 24 hours, so that any place on its surface will describe a circle in that time. From this it is clear that 360 degrees rotate in 24 hours, or 1 degree in 4 minutes. Assuming that the difference in time between any two places is known, their angular distance apart may be easily calculated by using this knowledge. The only difficult matter is the practical determination of the times of the two places—a difficulty that is increased because every place has two distinct times: (*a*) *clock time*, (*b*) *local time*. Clock time is also spoken of as **Greenwich mean time** (G.M.T.), while local time at Greenwich, which is taken from solar observations, and known as **Greenwich apparent** (or real) **time** (G.A.T.), differs from the local time at any other place by the time corresponding to the longitude.* These times differ because of the obliquity of the ecliptic, and the elliptical shape of the earth's orbit. The difference between the two is called the **equation of time.** It is clear, however, that when we are engaged finding local noon from observation of the sun, we can only express the exact moment of local noon by aid of a watch which records Greenwich mean time. This time must be converted by using the equation of time into Greenwich sun time or

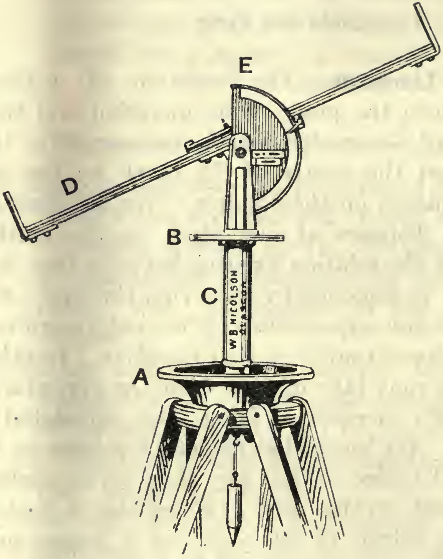

Fig. 32.

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* In 1916 Parliament passed an Act (renewed in 1917 and 1918) decreeing that in the summer months (April 1 to Sept. 30) Civil time should be one hour in advance of G.M.T. In other words, noon should be fixed by the moment the sun crosses the meridian of 15° E.

Greenwich apparent time before we can calculate the longitude of the place. For all calculations the equation of time may be obtained from a nautical almanac, and from the data there found a graph might be drawn for future use.

Determination of Local Noon.—The local noon of any place is determined by aid of the sextant or theodolite (fig. 32).* Erect the theodolite some time before noon and direct the sighting rod, *D*, towards the sun. Take the time of this observation by your watch, which presumably records Greenwich mean time. Rotate the sighting rod (taking care not to alter its elevation) and observe the sun after noon until you find that its direction is in a direct line with the rod. Note the time when this occurs. The mean of the two times thus found will give local noon at the place of observation *expressed as Greenwich mean time*. If reference be now made to "Whitaker's Almanack," this time may be converted into Greenwich apparent time by adding or subtracting the equation of time. It is only necessary to find the difference between the local noon thus obtained and Greenwich noon (12 o'clock) and convert this time into longitude, to arrive at the angular distance of the place of observation from Greenwich. If Greenwich noon is earlier than local noon, the longitude of the place is *east* of Greenwich; if Greenwich noon is later than local noon, the longitude is *west*.

To find the longitude of Newbury (Berks). We erected the theodolite and made our first observation of the sun's altitude at 9 hr. 50 min. 10 sec.

We made our second observation of the sun's altitude at 2 hr. 34 min. 30 sec.

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* This instrument is manufactured and sold by Messrs W. E. Nicholson, 166A, Bath St., Glasgow.

The mean of equal altitudes

$$= \frac{9 \text{ hr. } 50 \text{ min. } 10 \text{ sec.} + 14 \text{ hr. } 34 \text{ min. } 30 \text{ sec.}}{2}$$

$$= 12 \text{ hr. } 12 \text{ min. } 20 \text{ sec.}$$

Our watch was fast by Post Office time 4 min.

∴ Noon by G.M.T. = 12 hr. 8 min. 20 sec.

Equation of time (Jan. 1st) = − 3 min.

∴ Noon by G.A.T. = 12 hr. 5 min. 20 sec., *i.e.* the Greenwich time when the sun appeared directly over the meridian of Newbury. In other words Greenwich noon is later than local noon by 5 minutes 20 seconds. Hence the longitude of Newbury is *west* of Greenwich.

A difference in times of 5 min. 20 sec.

$$= \left(\frac{16}{3 \times 4}\right)^{\circ} \text{ difference in longitude,}$$

since 1° longitude = 4 minutes difference in time.

∴ Longitude of Newbury = 1° 20′ W.

Determination of Longitude.—(ii) Every large ocean-going vessel carries three chronometers keeping Greenwich mean time to ensure the correct reading of the times. The purpose served in carrying three is to enable the navigating officer of the ship to detect the slightest error in the time kept by any one of them, by comparing it with the other two. If by any possible chance they all get out of order, he can as a last resource determine his longitude from observation of the moon with the sextant. The moon makes a complete circuit in the heavens from east to west in $27\frac{1}{3}$ days. The angular distance it is away from any important star on any night may be obtained from the nautical almanac, the Greenwich apparent time corresponding to the angular distance being placed in a column opposite. Now, if the angular distance between the moon and the star be ascertained with the sextant, the Greenwich apparent time at the time and place of observation is readily obtained by noting the time given in the column opposite this angle in the almanac. The longitude of the place is then calculated in the ordinary way by subtracting the two times and converting the difference into angular measurement.

Determination of Distances.—Since the meridians converge towards the poles, the length of a degree of longitude becomes less as we leave the equator and approach the poles. At the equator the length of one degree of longitude is about 69·15 statute miles, at latitude 50° the length of one degree is about 44·55 statute miles, while at the poles it is zero. It is clear, therefore, that we should have some method of calculating in miles the distance between two places when their latitude and longitude are given. In such calculations we may consider the earth to be a perfect sphere and that the length of a degree of latitude in miles is constant. Assuming this to be so, we need only consider two cases in determining the distance between any two places on the earth's surface.—(i) when the two places are situated on the same parallel of latitude but are

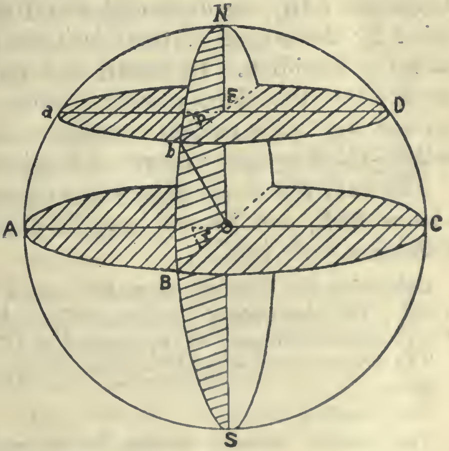

FIG. 33.

in different longitude, (ii) when the two places are not on the same parallel of latitude nor on the same meridian.

(i) Assume that the earth is a true sphere with O as centre (fig. 33), NAS and NBS two meridians cutting the planes abD and ABC at right angles. The angle p subtended at E by the arc ab is equal to the arc ab, and the angle r subtended at O equals the arc AB. Since the plane ABC represents the Equator, the length of the arcs NA, NB is each 90°. Also the lengths of the circumference of any two circles are proportional to their radii. Therefore:

$$ab : bE :: AB : BO$$

$$\frac{ab}{AB} = \frac{bE}{BO} = \frac{bE}{bO} = \sin\ bOE$$

$$= \sin \text{ of arc } bN = \cos\ (90° - bN) = \cos\ bB$$

$$\therefore\ ab = AB \cos\ bB$$

That is, the distance between two places situated on the same parallel of latitude equals their difference in longitude (AB), as measured along the Equator multiplied by the cosine of their latitude ($\cos bB$) measured along a meridian. In order to arrive at the distance between the two places in statute miles, the result obtained on solving this equation should be multiplied by 69·15 miles—the length of a degree of longitude at the Equator.

The rule which we have just enunciated is called the *Cosine Rule*, and its use may be clearly seen from the following exercise.

Determine the distance in statute miles between Carlisle and Vilna. The longitude of Carlisle is 3° W., of Vilna 25° E., while both towns are situated on the parallel of 55° N. latitude.

The difference of longitude between Carlisle and Vilna = 3° + 25° = 28°.

Their latitude = 55°.

The distance between them = diff. of long. × cos lat.
= 28° × cos 55°.

The distance between them in statute miles = 28° × Cos 55° × 69·15.

$$\text{Cos } 55^\circ = 0\cdot5736.$$

$$\begin{aligned}\therefore \text{ The distance} &= 28 \times \cdot5736 \times 69\cdot15 \text{ miles.}\\ &= \text{Antilog } (1\cdot4472 + \bar{1}\cdot7586 + 1\cdot8398)\\ &= \text{Antilog } (3\cdot0456)\\ &= 1{,}111 \text{ miles.}\end{aligned}$$

The distance between Carlisle and Vilna = 1,111 miles (approximately).

(ii) (*a*) In the case when the two places are not on the same parallel of latitude it is more difficult to ascertain their distance apart in miles. Imagine A_1PB_1 (fig. 34) to represent a part of earth's surface, P being a pole and A_1B_1 a portion of the Equator. Suppose we are given the latitudes of two places A and B and their difference of longitude APB, and require to find the distance AB. Those students who have a knowledge of spherical trigonometry will know the formula for spherical triangles:

$$\text{Cos } a = \cos b \cos c + \sin b \sin c \cos A.$$

$$\text{Cos } AB = \cos AP \cos BP + \sin AP \sin BP \cos APB.$$

AP, BP are the co-latitudes and are therefore known. Hence AB may be determined in degrees and converted to miles by multiplying by 69·15.

(*b*) There is, however, a simpler method which will give us an approximation only, and which is accurate when the distance AB is so small that ABC (fig. 34) and ABD may be considered as plane triangles. This rule is generally spoken of as the *Mid-Latitude Rule*, and may be expressed as follows:

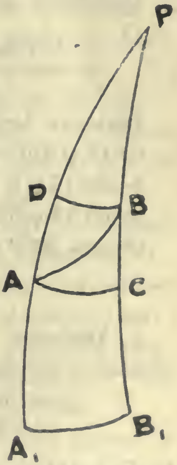

FIG. 34.

The distance $= 69{\cdot}15 \times \sqrt{l^2 + (D \cos L)^2}$

where l = difference in latitude in degrees

D = difference in longitude in degrees

L = average latitude.

In the triangle ABC (fig. 34) $AB^2 = AC^2 + BC^2$, or $AB^2 = BD^2 + AD^2 = BD^2 + BC^2$. $AC = A_1B_1 \cos l_1$, $BD = A_1B_1 \cos l_2$, where l_1, l_2 are the latitudes of A and B. A nearer approximation to AB^2 is given by taking the mean value between AC and BD, *i.e.* $A_1B_1 \cos L$ or $D \cos L$.

Hence $AB^2 = l^2 + (D \cos L)^2$ or $AB = \sqrt{l^2 + (D \cos L)^2}$ measured in degrees, or $69{\cdot}15 \times \sqrt{l^2 + (D \cos L)^2}$ miles.

Calculate the distance in statute miles between Nottingham and Neuchâtel. Nottingham is situated in latitude 53° N., longitude 1° W.; Neuchâtel in latitude 47° N., longitude 7° E.

Difference in latitude $= 53° - 47° = 6°$

Difference in longitude $= 1° + 7° = 8°$

$$\text{Average latitude} = \frac{53 + 47}{2} = 50°$$

$$\text{Cosine } 50° = 0{\cdot}6428.$$

Distance between Nottingham and Neuchâtel =

$69{\cdot}15\sqrt{\text{diff. of lat.}^2 + (\text{diff. of long.} \times \text{cos av. lat.})^2}$ miles

$= 69{\cdot}15\sqrt{6^2 + (8 \cos 50°)^2}$ miles

$= 69{\cdot}15\sqrt{36 + (8 \cos 50°)^2}$ miles

$(8 \cos 50°)^2 = \text{antilog } 2 \times ({\cdot}9031 + \bar{1}{\cdot}8081)$

$= \text{antilog } 1{\cdot}4224$

$= 26{\cdot}44$

∴ Distance in miles between Nottingham and Neuchâtel $= \text{antilog } (1{\cdot}8398 + \frac{1}{2} \times 1{\cdot}7955)$

$= \text{antilog } (2{\cdot}73755)$

$= 546{\cdot}5$ miles.

The distance between Nottingham and Neuchâtel = 547 miles (approx.).

Exercises on Longitude

1. Ascertain the longitude of your school by the method explained in the chapter.
2. Calculate accurately the length of a degree of longitude in miles at London (lat. 51½° N.).
3. Find the approximate distance of two places, one on the Equator in east longitude 33°, and the other in north latitude 33° and east longitude 10°. (Coll. of Preceptors.)
4. Cairo (Egypt) is 30° N. lat., 30° E. long. How far is Cairo from the Equator, and what is the clock-time there when it is noon at Greenwich?
5. Why does the length of a degree of longitude differ so much in various parts of the world?
6. Arrange the following places in two columns: (1) those having noon before Greenwich, (2) those having noon after Greenwich. Do not look at your atlas till the columns are complete. Aberdeen, Ipswich, Barcelona, Petropaulovsk, Fiji Islands, Gibraltar, Honolulu, Lagos, St. Helena.
7. Explain, using one or more diagrams, "correction for parallax." [*E.g.* in taking observations of the moon for longitude.]
8. When it is 4.30 p.m. on the meridian of Sydney (Cape Breton), what is the time at Greenwich?
9. Explain the following terms, making the distinctions between terms in the same group quite clear: (1) Solar day, mean solar day, sidereal day. (2) Mean time, apparent time, local time. (3) Clock time, Greenwich time, sundial time.
10. Calculate the approximate distance of two places in miles, one of which is in north latitude 20° and east longitude 40°, while the other is in south

latitude 30° and east longitude 60°. (Coll. of Preceptors.)

11. If the time at Vienna be 3.47 p.m., where is it midnight, and if at Constantinople the time be 4.43 a.m., where is it noon?
12. A steamer sails from San Francisco to Yokohama in 800 hours. At what rate will a watch on board gain?
13. What is the *equation of time*, and what use is made of it?
14. What is meant by the expression "standard time"? Explain why ships carry chronometers keeping a standard time for the purpose of determining their longitude. (Oxf. and Camb. Sch. Cert.)
15. When it is 12 o'clock in London, what is the time in two places, one of which is in 45° east longitude, and the other in 75° 36′ west longitude? Explain the reason for this difference.
16. Define "latitude" and "longitude." What instruments are used on board ship to determine latitude? Explain (in their simplest form) the observations which are taken, and the calculations which have to be made. (Royal Irish Constabulary Cadets.)
17. The result of a cricket match played by an English team at Melbourne in Australia (longitude about 145° E.), which only finished at 6 p.m., was known here early in the same afternoon. Explain this. (Camb. Jun. Loc.)
18. How can the length of a degree of longitude be found mathematically, say at a latitude of 60 degrees? What is the distance round the earth along the parallel of 60 degrees? (Coll. of Preceptors.)
19. Explain what is meant by saying: (*a*) Naples and Prague have the same *longitude*. (*b*) Birmingham

and Berlin have the same *latitude*. (*c*) The time at Dublin is 25 minutes slow by Greenwich. (Coll. of Preceptors.)*

20. Find the approximate distance of two places, one on the Equator in east longitude 33°, and the other in north latitude 33° and east longitude 10°. (Coll. of Preceptors.)
21. When it is 2 a.m. on Thursday at Greenwich it is 9 p.m. on Wednesday at Ottawa and noon on Thursday at Sydney. Calculate the longitude of these places. (Camb. Jun. Loc.)
22. Cape Farewell, in Greenland, is in west longitude 43° 54′; and St. Petersburg is in east longitude 30° 18′. Both places are nearly on the same parallel 60° N. Show how you would calculate their distance in miles from each other, either east or west. (Coll. of Preceptors.)
23. Find the latitude and longitude of a place which is 1,000 miles east of Greenwich and 500 miles north of the Equator. (Coll. of Preceptors.)
24. At an observatory situated in the northern hemisphere the following observation was made:

    On December 21 the sun was observed to reach its greatest altitude (16·5°) at 2 p.m. (Greenwich time). Explain how the latitude and longitude can be determined from the observation, and make the necessary calculations. (Oxf. Sen. Loc.)
25. At the vernal equinox a sailor in the northern hemisphere finds the elevation of the sun at midday to be 38°. What is his latitude? How may he determine his longitude? (Civil Service.)
26. Calculate the approximate distance of two places in miles, one of which is in north latitude 20°

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* In 1916, by Act of Parliament, Irish time was made the same as that of Great Britain.

and east longitude 40°, while the other is in south latitude 30° and east longitude 60°. (Coll. of Preceptors.)

27. What do you understand (*a*) by the sun crossing the meridian, (*b*) by Greenwich time?

    A man travelling from London to Berlin notices on his arrival that there is a difference of one hour between his watch and German time. How is this?

    The longitude of Bombay is 75° 20′ E., of Charlestown 80° 40′ W. What time is it at each of these places when it is noon at Greenwich? (Civil Service.)

28. Find the approximate distance in miles between two places, one in 40° N. latitude and 3° E. longitude, and the other in 50° S. latitude and 150° W. longitude. (Coll. of Preceptors.)

29. Explain why the length of a degree of latitude is nearly the same in all latitudes, while that of a degree of longitude diminishes as latitude increases. (Oxf. Jun. Loc.)

30. Explain how one's position may be determined by observation of the moon.

31. How can the distance in miles near London be found between (*a*) one parallel of latitude and the next, (*b*) one meridian and the next? What are the approximate distances? (Coll. of Preceptors.)

32. What is longitude, and how does it affect time? What would be the local time and day in Japan (time of 145° E.) and Jamaica (time of 75° W.) corresponding to Greenwich mean time 6 p.m. Monday? (Camb. Jun. Loc.)

33. Explain how you would find the Pole Star; and how, having found it, you could determine your latitude. (Camb. Sen. Loc.)

34. When it is noon at Greenwich, what time will it be at 30° S., 30° W., and at 66½° N., 160° E.? What will be the height of the sun at local noon at these two spots on June 22? (Oxf. and Camb. Sch. Cert.)

35. If the time on the top of a hill be 6 p.m. when it is noon at Greenwich, in what longitude is it? If the sun be vertically overhead on June 20, what is its latitude? (Civil Service.)

36. At a certain place on December 25 the sun attained its maximum altitude, which was 14°, at 12.5 p.m., Greenwich mean time. The declination of the sun on the day in question was 23½° S. Find the latitude and the longitude of the place where the observations were made. (Camb. Sen. Loc.)

37. Describe any simple method by which you could determine approximately the latitude of the place you live in. What is the highest point above the horizon reached by the sun in latitude 57½° at (*a*) midsummer, (*b*) midwinter? (Camb. Sen. Loc.)

38. What is meant by the terms "nadir" and "zenith"? At what part of the earth would an observer see the Pole Star in his zenith? (Oxf. Jun. Loc.)

39. A ship which sails from London to New Zealand round the Cape of Good Hope makes no change in its calendar, but while returning to London round Cape Horn the calendar is altered by one day so as to agree with the English reckoning. Why is this done? (Camb. Jun. Loc.)

40. On June 21 the altitude of the sun is 45°, the direction south. What is the latitude and what would be the altitude at noon on December 21? (Camb. Jun. Loc.)

CHAPTER X

Shape and Size of the Earth

THE earth is a round or spherical body. Many well-known proofs have been advanced to prove this. Of these, that which appears to be the most conclusive is the result of an experiment actually performed on a six-mile section of the Old Bedford Level which joins Earith on the Great Ouse to Denver. This Old Level is a straight stretch of still water, and most suitable for the test of the sphericity of the earth. Midway between Denver and Welney a pole (15 feet), of the same height as the parapet of Welney Bridge, was fitted on a raft. By the aid of a telescope a mark, of the same height on Denver Bridge, was sighted from the top of Welney Bridge, and the pole was found to be 6 feet above the line of vision. That is—the top of the pole did not come into the line of vision till it was lowered 6 feet below the level of the telescope.

Earth an Oblate Spheroid.—Although the above experiment establishes the earth's rotundity, it does not in any way give us a clear idea of its exact shape. From the triangulation of geodetic surveys arcs of meridians have been measured in different latitudes, and from the different lengths on the surface of the earth of arcs of 1° it has been concluded that the true shape is that of an **oblate spheroid.** Geologists account for this by supposing that the earth in its earliest stages was a viscous body which, through rotation, became compressed at two opposite points on its surface. That they have probably been correct in their assertion is supported by the fact that the length of a degree of latitude varies according to the latitude. This variation was shown to exist in the following manner: Two degrees of latitude were chosen, one near the Equator, the other near the Pole. By means of the theodolite the length of each degree was carefully measured by triangulation, and the result showed that the degree of latitude near the Equator was less than that more remote. Hence the curvature of the earth is less marked near the poles than at the Equator. The actual difference between a degree of latitude at the poles and one near the Equator is about $\frac{7}{10}$ mile.

A further proof of the earth's spheroidal form has been arrived at by observing the intensity of the force of gravity at certain places on its surface. A simple pendulum of delicate construction will beat at a faster rate in "high" latitudes than in "low" ones. This is because the intensity of the force of gravity becomes more marked in proportion as the pendulum is removed from the Equator towards either pole. If the earth were a true sphere, the force of gravity would be constant for all places on its surface. Hence we conclude that places situated in the polar regions are nearer the earth's centre than those at the Equator, and that the polar diameter is less than an equatorial diameter. It has been estimated that the compression is about 13½ miles at each pole, so that the polar diameter is about 27 miles shorter than the equatorial diameter.

The Equatorial Circumference.—The lengths of the equatorial and polar diameters have been calculated by determining the earth's circumference as traced (*a*)

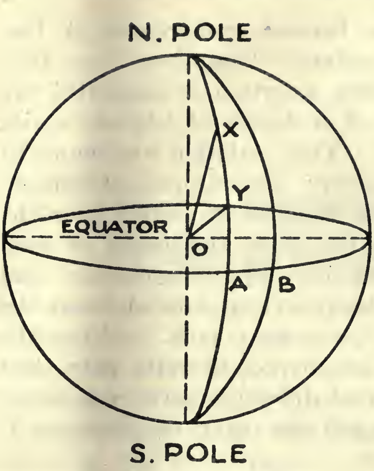

FIG. 35.

along the Equator, (*b*) along a meridian. In computing the length of the equatorial circumference of the earth two points *A* and *B* (fig. 35) were chosen some distance apart on the Equator. The times when a certain star appeared over the meridians, *NAS*, *NBS*, were noted. This was done by taking observations of the star with the theodolite. Now from the difference between the times of each observation, the number of degrees in the arc *AB* was readily computed, and the distance in statute miles between the points *A* and *B* was then measured by the theodolite by means of triangulation. In the diagram it is seen that:

$$\frac{\text{Arc } AB}{360^\circ} = \frac{\text{length of } AB \text{ in miles}}{\text{length of Equator in miles}}$$

$$\text{Hence the Equator} = \frac{AB \times 360^\circ}{\text{Arc } AB} \text{ miles.}$$

The actual calculation resulted in the length of the equatorial circumference being thus found to be about 24,800 miles. Consequently the length of the equatorial diameter $= \frac{24{,}800}{\pi} = 8{,}000$ miles approximately, or more accurately 7,926·6 miles.

Experiment of Eratosthenes.—Eratosthĕnes, a librarian of Alexandria (276–196 B.C.), one of the most learned men of antiquity, was practically the founder of scientific geography. He was the first to attempt the accurate measurement of the size of the earth. Before his time it had been shown by Eudoxus (called by Cicero the "Prince of Astronomers") and other astronomers that the earth was globular. They pointed out that, when a man travelled northwards, stars, which when he started had been low on the horizon, were seen to rise higher and higher in the sky, and stars which to start with were overhead, appeared to go down and occupy a lower position towards the south. This they rightly took to be a clear proof that the surface of the earth was curved. They, however, made the earth the fixed centre of the universe. Many guesses were made at the circumference of the sphere. Aristotle, for example, mentions the conclusion arrived at by a certain mathematician, whom he does not name, to the effect that the circumference was 400,000 stadia, which at 10 stadia to the mile is 40,000 miles. But Eratosthenes attempted something more than a guess. He made careful measurements and careful calculations. Being informed that at Syene (now Assouan) a certain well* was, at noon on the day of the summer solstice, always completely lit up from top to bottom, he concluded that Syene was on the northern tropic, and that therefore the sun's zenith distance at that time would be zero. He measured at the hour of noon of the summer solstice the zenith distance of the sun at Alexandria and found it to be 7° 12′. That is, the arc of the angle M (7° 12′)=

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* Professor John Garstang a few years ago discovered in Egypt an observatory at the bottom of an underground bathing establishment. It was a copy of the well at Assouan. On the walls the astronomer had left some of his calculations, and his servant had left some drawings of his master at work.

arc of the angle *BOZS* (fig. 36), which represented the 5,000 stadia from Alexandria to Syene. Hence by proportion:

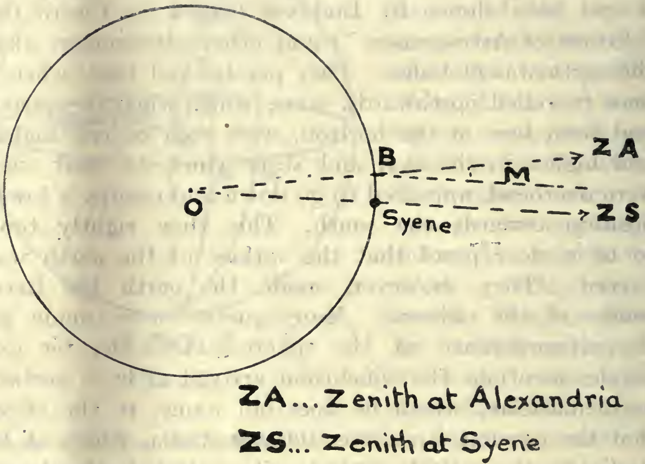

FIG. 36.

$$\text{Circumference of earth} = \frac{5{,}000 \times 360}{7\frac{1}{5}} \text{ stadia}$$

$$= \frac{5{,}000 \times 360 \times 5}{36} \text{ stadia}$$

$$= 5{,}000 \times 50 \text{ stadia}$$

$$= 250{,}000 \text{ stadia}$$

$$= 25{,}000 \text{ miles } (10 \text{ stadia} = 1 \text{ mile}).$$

This was indeed a result very striking in its general accuracy when it is remembered that his calculation involved several errors:

i. His angle was too large. (See diagram of apparatus, fig. 37.)

ii. He considered that Alexandria and Syene were on the same meridian, and they are not.

iii. He believed the earth was a perfect sphere, which it is not.

iv. He considered Syene was directly under the Tropic of Cancer, whereas it is 37 miles north of it.

v. He over-estimated the distance between Syene and Alexandria.

The apparatus that Eratosthenes employed to measure the sun's zenith distance, although novel in design, could not give sufficiently accurate measurements for the purpose in view. It consisted of a semicircular scaphe or bowl (fig. 37) with a gnomon in the centre.

The concave surface of the globe was graduated, reading upwards from 0° to 90° on each side of the gnomon. The arc marking the shadow cast by the gnomon is obviously equal to the angle *M*—the sun's zenith distance. In practice such an apparatus could only give a very rough reading, and this explains to some extent the error Eratosthenes made in obtaining too large an angle. In the diagram, for convenience in drawing, the arc of the shadow is shown about 7 times the angle

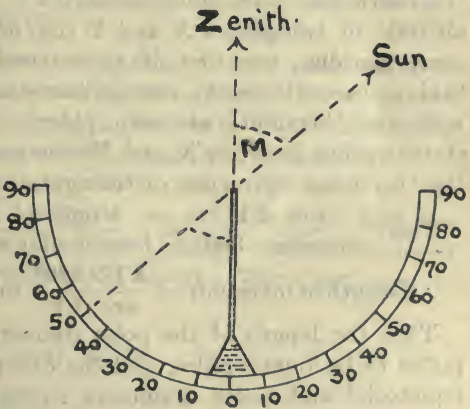

Fig. 37.

observed by Eratosthenes. A later estimate made by the Egyptian astronomer Ptolemy about 160 A.D. gave the circumference of the world as 18,000 miles. The error was caused by his taking 50 geographical miles as the length of a degree instead of 60. That is, if he was informed by sailors, merchants, explorers, etc., that the distance between two places was 50 miles, he would mark those places on his map as one degree apart. The consequence of this was that the distance on Ptolemy's map—which Columbus used *—between Western Europe westwards to Eastern Asia was reduced to about one-third of the total circumference of the earth, whereas it should have been two-thirds. This is why Columbus so naturally concluded that after his voyage of about 5,000 miles he had reached India.

The Polar Circumference.—The polar circumference of the earth has been thus calculated: The difference in altitude of two places *X* and *Y* (fig. 35) situated on the same meridian was first of all determined by means of taking observations of a certain star—say the Pole Star—with the theodolite at each place. The distance in statute miles between *X* and *Y* was next measured with the theodolite by means of triangulation.

$$\text{Then } \frac{\text{arc } XY}{\text{meridian } 360^\circ} = \frac{\text{length of } XY \text{ in miles}}{\text{length of meridian in miles}}$$

$$\therefore \text{Length of meridian} = \frac{XY \times 360^\circ}{\text{arc } XY} \text{ miles.}$$

Thus the length of the polar diameter has been computed to be 7899·6 miles, and the difference between the equatorial and polar diameters is, therefore, 7,926·6 − 7,899·6 = 27 miles.

Earth Measurements.—Knowing the radius of the earth, and neglecting the small difference between the equatorial and the polar diameters, we are thereby enabled to make some interesting calculations respecting the earth's dimensions. If we assume the earth's radius to be 4,000 miles, then the area of its surface $= 4\pi r^2 = 4\pi(4{,}000)^2$ $= 4 \times 3{\cdot}14159 \times 16 \times 10^6$ square miles. The area of a hemisphere is therefore $2 \times 3{\cdot}14159 \times 16 \times 10^6$ square miles.

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* The map used by Columbus was really that of Toscanelli, which was based upon the error of Ptolemy.

On every globe representing the earth we find meridians and parallels of latitude drawn thereon. These lines assist us in determining positions on the sphere, and facilitate measurements and calculations. For example, any two meridians enclose an area called a **lune**, whose surface area may be determined from the following proportion :

The area of lune : area of sphere : : angle of lune : 360°

$$\text{Hence area of lune} = \frac{\text{area of sphere} \times \text{angle of lune}}{360^\circ}$$

(The angle of the lune is the angle between the planes of the two meridians bounding the lune. It is measured by the angle subtended at the centre of the sphere by the arc of the equator between the two meridians.)

The value of this formula may be seen in the following exercise. Suppose we are asked to find the area of that portion of the earth's surface enclosed between two meridians 15° apart. Then the area of surface required

$$= \frac{4\pi r^2 \times 15}{360} \text{ sq. miles}$$

$$= \frac{4 \times 3{\cdot}14159 \times 16 \times 10^6 \times 15}{360} \text{ sq. miles}$$

$$= \frac{4 \times 3{\cdot}14159 \times 2 \times 10^6}{3} \text{ sq. miles}$$

$$= \tfrac{1}{3}(8 \times 3{\cdot}14159 \times 10^6) \text{ sq. miles.}$$

Other earth measurements which depend upon the determination of its radius are its volume and its mass. The volume of a sphere $= \frac{4}{3}\pi r^3$. Therefore the volume of the earth $= \frac{4}{3} \times 3{\cdot}14159 \times 64 \times 10^9$

$= $ about 260,000,000,000 cubic miles.

But since the mass = density × volume, we can find the earth's mass when we have determined its density.

The Density and Weight of the Earth.—About one hundred years ago Cavendish determined the earth's density by what is styled as the "torsion-balance" experiment. He fixed two small leaden balls to the ends of a light, rigid rod, and suspended the rod by a fine silver wire attached to its centre. Two large leaden balls a foot in diameter were then brought close to the small balls so that their attraction tended to twist the fine wire. In this way the small balls were pulled out of their original position and the amount of deviation measured. The weight of the small balls was a measure of the earth's attraction upon them, and since the distance of the small balls from the earth's centre was known, the mass of the earth was estimated from the known mass of the two large leaden balls. Experimenting in this way, Cavendish calculated the earth's density to be 5·7, that is, slightly over 5½ times an equal volume of water. The experiment of Cavendish has been repeated many times by subsequent physicists, and it is important to note how remarkably consistent are the values obtained. The average of the nine most reliable values is 5·48, which differs by very little indeed from Cavendish's result. Now the volume of the earth has been stated to be about 260,000,000,000 cubic miles, and the weight of a cubic mile of water is about 4,100,000,000 tons. Therefore the earth's weight $= 260{,}000{,}000{,}000 \times 4{,}100{,}000{,}000 \times 5{\cdot}5$ tons.

The Dip of the Visible Horizon.—Everyone is familiar with the fact that the higher one ascends above the surface level of the earth, the greater is his range of vision, or, to put it in other words, the limit of one's visible horizon depends upon one's altitude. In the estimation of the distance of the visible horizon we must take into consideration the earth's radius. Let *A* be a point at a distance *h* (fig. 38) above the earth, and *O* the centre of the earth. The limit of the visible horizon as seen from *A* will be the tangents *AR* and *AT* drawn to the circle. If a line *AN* be drawn at right angles to *AO*, what we call the **dip of the horizon,** or the **Offing,** is represented by the angle *TAN* $= AOT$. Now to find the distance of the visible horizon, that is, the length of *AT*:

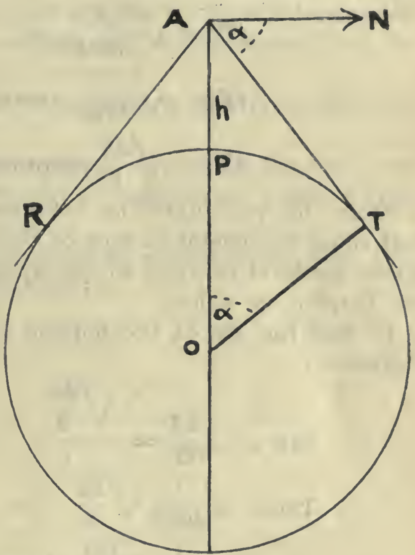

FIG. 38.

$$AT^2 = AP \times AS \text{ (Euclid III. 36)}$$
$$= AP\ (AP + PS)$$
$$= AP\ (AP + 2r),$$ where r is the radius of sphere. Since *AP* is so small in comparison with the

diameter of the earth, its value may be neglected when taken with it. Then—

$$AT^2 = AP \times 2r$$
$$AT = \sqrt{h \times 2r}$$

The value of r is in miles and of h in feet, so that the equation may be stated :

$$AT = \sqrt{\frac{h}{5280} \times 2r}$$
$$AT = \sqrt{\frac{h}{5280} \times 8000}$$
$$\therefore AT = \sqrt{\frac{3h}{2}} \text{ (approximately).}$$

From this we obtain the following rule : One and a half times the height in feet of the place of observation above sea-level is equal to the square of the distance of the horizon in miles.

To find the dip of the horizon as seen from a given elevation :

$$\text{Tan } \alpha = \frac{AT}{OT} = \frac{\sqrt{\frac{3h}{2}}}{r}$$
$$\therefore \text{Tan } \alpha = \frac{1}{4000}\sqrt{\frac{3h}{2}}$$
$$\therefore \alpha = \frac{1}{4000}\sqrt{\frac{3h}{2}} \text{ (approximately).}$$

EXERCISES

1. Describe the change in the apparent positions of the Pole Star as an observer moves from the Equator to the North Pole. How does the change of position help us to determine the size of the earth ?

2. "If with the naked eye an observer can see an object three miles distant, with a sufficiently powerful telescope he could from the same point of observation see an object six miles distant." Is this statement true? If it is, what bearing has it upon the theory of the earth's sphericity?
3. If two plumb-lines were suspended from a horizontal pole at a distance apart of 6 feet, would they be parallel?
4. Describe a method of measuring the circumference of the earth.
5. The earth's shape is an oblate spheroid. Give at least two scientific proofs to establish the truth of this statement.
6. How may it be determined by measurement that the earth is not spherical?

PART II

THE ATMOSPHERE

CHAPTER XI

Nature and Constitution of the Atmosphere

Height of the Air.—By atmosphere we mean the world of vapour. The common name for atmosphere is air. The air surrounds the whole earth, covering both land and sea, and reaching upwards to an unknown height. This atmospheric envelope is the region in which are formed the clouds, where occur the lightning and the thunder, and where originate winds, storms, and tempests. No limit of height can be fixed for it; indeed its height above the earth may be considered to vary according to the point of view. To the aviator, seven miles seems to be about the limit, since beyond that height it is so thin that it will not support life. Between 1862 and 1866 James Glaisher, an English meteorologist, made twenty-eight balloon ascents for the purpose of studying the upper air, and on one occasion reached a height of over seven miles. In June 1913 Messrs Bienaimé and Schneider, wearing an oxygen apparatus, ascended more than six miles. Duration of twilight depends partly upon the angle at which the sun's rays strike the atmosphere and partly upon the thickness of the atmosphere (see p. 31). From the phenomena of twilight astronomers find that the atmosphere extends at least forty-five miles above the earth. In the case of meteors entering the atmosphere from outer space, so long as they meet no air they develop no heat by friction, and therefore emit no light-waves. Hence, as soon as the meteors become visible, we know they have entered the atmosphere where it is sufficiently dense to produce enough friction to make them visible. Determination of the height at which these meteors become luminous gives the atmosphere a height of 200 miles. The density of the air diminishes gradually, and the process of diminishing goes on gradually, so that it would be at a very great height indeed where it could be said there was no air at all. If there were no atmosphere, there would be nothing either to refract or to reflect the rays of the setting sun (see Chap. IV), and we should be in black darkness the moment the sun sank below the horizon.

Ingredients of Air.—The air is not, as was at one time supposed, an element, but a mixture (not a compound) of two chief elements together with small quantities of other ingredients. The two chief elements are **oxygen** and **nitrogen.** Oxygen is the element which (*a*) sustains the life of air-breathing animals, (*b*) supports combustion, and (*c*) is one of the agents promoting the crumbling of exposed rocks into soil. Take a piece of phosphorus the size of a pea and dry it between blotting-paper. Be careful not to touch the phosphorus with the fingers, but cut it under water and remove the piece with the point of the knife. Place the piece of phosphorus upon a large, flat cork and float it in a trough of water. Cover the floating cork and phosphorus with a stoppered bell-jar, take out the stopper and set light to the phosphorus by touching it with a red-hot wire. Replace the stopper immediately and watch for a rise of water under the bell-jar. At first the water will sink a little, because the air expands under the heat of the burning phosphorus. Soon it will commence to rise steadily. As soon as the phosphorus has ceased to burn and the jar has become cool, measure how much of the former air-space inside the jar is now filled by the risen water. You will find it to be about one-fifth. From this you will see that something has been taken from the air, and that this something (which was a gas that supported the combustion of the phosphorus) occupied one-fifth of the volume of the air. The gas in question was **oxygen.** Let the bell-jar stand till all the white fumes (phosphorus pentoxide) have disappeared from view. Four-fifths of the space inside the jar is still occupied by an invisible gas. Pour water into the trough outside the jar until it reaches the level of the water inside the jar. Remove the stopper and with a deflagrating spoon introduce a fresh piece of burning phosphorus. It ceases to burn. Put a lighted match carefully inside the jar. It at once goes out. It is plain, then, that the gas that occupies the remaining four-fifths of the space inside the jar will not support combustion. This gas is **nitrogen.** More accurately, the proportion of the one gas to the other is 20·61 parts by volume of oxygen to 77·95 parts by volume of nitrogen in every 100 parts by volume of air. The remaining parts consist of carbonic acid gas, water vapour, together with traces of other gases. There is a slight variation in the ratio of nitrogen to oxygen in different localities. There is a diminution in the percentage of oxygen in large towns because of the increased percentage of other gases, such as carbonic acid gas, breathed out by the inhabitants, and such as the fumes from factory chimneys. In crowded rooms the carbonic acid gas breathed out by those present lowers the percentage of oxygen, as does the escape of imprisoned rock gases in caves and mines. In foggy weather the large amount of water-vapour present has the same effect. The function of the nitrogen is to modify or dilute the action of the oxygen, which, if present alone, would be too powerful for the support of animal life.

Besides these two chief gaseous ingredients, there is in the air a varying small quantity of **carbonic acid gas** (carbon dioxide), which though small in quantity is of great importance. In 1894 it was discovered by Lord Rayleigh and Professor (now Sir William) Ramsay that about 1 per cent. of what in the air was supposed to be nitrogen is really a new substance so much like nitrogen in every respect that until then it had escaped detection. This gas they named argon. In 1898 Professor Ramsay announced the discovery of traces of a further new constituent in the atmosphere. This he called krypton. This, like argon and nitrogen, is a very inert gas. Since then small traces of other gases, such as helium, neon, xenon, and niton * have been discovered, but their functions are not yet clearly known.

It would seem from the paper read at Rome in June 1913 by Sir William Ramsay that these more recently discovered constituents of the atmosphere are intimately connected with hydrogen. Although they have hitherto been regarded as elements, they should be looked upon as compounds of hydrogen with other elements. For example, he has obtained argon from hydrogen and sulphur by submitting them, in contact, to the action of the cathode rays. Similarly he has made krypton from hydrogen and selenium, and has caused hydrogen and oxygen to unite to form neon. Helium in all probability must be regarded as a polymer of hydrogen, that is, it consists of the same kind of stuff but with different properties which must be attributed either to the different densities (helium being four times as dense as hydrogen) or to increased molecular complexity.

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* The names of these gases indicate the uncertain state of our knowledge of them: *neon*, something new; *argon*, something inactive; *krypton*, something hidden; *xenon*, something strange; *niton*, which is possibly intended to mean something shining.

Carbon Dioxide.—Carbon dioxide is a tasteless, odourless gas that neither burns nor supports combustion. It is the same as the choke-damp so often present in mines. It is present in the atmosphere to the extent of about ·04 per cent. Air containing over 7 per cent. of this gas would be a fatal poison and would produce insensibility and death. The presence of the gas in the air may be proved by experiment. Place a shallow dish of lime-water in the open air for a few hours. At the end of this time there will have formed a thin, solid film of carbonate of lime upon the surface of the water. The carbon dioxide of the air has combined with the lime in the water to form this solid. Take a tumbler of lime-water and breathe into it through a glass tube. The water instantly becomes milky, and this condition is due to the formation of carbonate of lime, and proves the presence of carbon dioxide in the air breathed from our lungs. Place a growing plant (a small lettuce plant will do) in a shallow dish of water, and cover it with a stoppered bell-jar. Fill the jar with carbon dioxide, and before replacing the stopper, introduce a lighted taper—it is instantly extinguished. Expose the apparatus for a few hours to the sunshine. Again introduce the lighted taper. This time it will burn in the jar. This shows that the growing plant has used up some of the original carbon dioxide, and has given out in exchange some oxygen. Hence, growing plants purify the atmosphere by extracting the carbon dioxide, and by retaining the carbon to build up their solid parts. The oxygen of the carbon dioxide they give back to the air in a free state for the use of animals and man. The supply of carbon dioxide in the air comes from the respiration of animals, and at night of plants, from decaying animal and vegetable matter, from the combustion of coal, wood, and all substances containing carbon, from the soil, and from volcanoes. If the supply were greatly increased, injury would result to animals and men; if the supply were greatly diminished, injury would result to all forms of vegetation. The maintenance of this wonderful biological balance is part of the **harmony of nature.**

Water-vapour in the Air.—Besides the oxygen, nitrogen, carbon dioxide, and other dry gases, there are always present in the air two other substances which cannot be considered as ingredients of pure air. These are **water-vapour** and **dust.** Water-vapour is water in its invisible, gaseous form. The process by which any liquid changes into its vapour is called **evaporation,** and the rate at which it takes place varies according to certain conditions. The chief of these conditions are the temperature of the air and the extent of water-surface presented to the air. As a rule, the higher the temperature of the air, the greater the rate of evaporation. There is, however, a limit to the amount of water-vapour that the air can hold at any time and place, and when the limit is reached, the air is said to be **saturated.** Therefore, the most favourable conditions for the production of water-vapour are unsaturated, warm air in contact with a water-surface. If upon a land surface the amount of water in the form of rivers, lakes, marshes, and the like be small, the air in those places remains comparatively dry; but over large bodies of water such as oceans and seas, especially in warm latitudes, the conditions are favourable to saturation of the atmosphere. But into regions where the air would otherwise be dry, moisture may be brought by winds that blow from the ocean. The presence of water-vapour in the air can be easily detected, and the vapour itself removed by the following method. Place a little dry chloride of calcium in a watch-glass, and balance it in a pair of scales. The chloride of calcium absorbs water-vapour freely from the air. The gradual falling of the scale-pan shows that the chloride of calcium is becoming heavier by this absorption of vapour. Substances like chloride of calcium and sulphuric acid that are capable of taking up moisture from the air are called hygroscopic. The presence of water-vapour in the air has the effect of keeping the earth warmer than it would be if there were none. For although the vapour acts as a screen between the earth and the sun during the day, at night this same screen prevents the earth from giving off its heat into space.

If saturated air be cooled it can no longer hold all its vapour, and a portion of it changes back to water. This process is called **condensation.** If condensation takes place at a temperature above freezing-point, tiny globules of water are formed; but if the temperature be low enough, minute crystals of ice are formed instead. If it were not for this process of condensation, not only would the whole atmosphere be in a state of permanent saturation, but there would also be a permanent diminution of the surface-waters of the earth, corresponding to the amount permanently in the atmosphere. Evaporation and condensation are, however, the two processes which underlie the great circulation of the waters of the earth. By evaporation water is taken up from every ocean, sea, lake, and river as vapour; by condensation followed by precipitation as rain, snow, and hail it returns to the earth to fill again the rivers, lakes, and seas.

Dust in the Air.—Besides the gaseous matter in the air there is a solid constituent, which is present in such minute particles that its presence is usually overlooked. The general name for these solid particles is **dust.** But when we speak of the dust of the air, we do not refer to the temporary clouds of visible and offensive fragments stirred up by motor-cars, high winds, carpet beaters, and other unpleasant agencies. There is, besides this, a fairly constant, invisible, solid constituent of the air which may be called microscopic dust, or dust-motes. The sources of this dust are many. When wood, coal, or vegetable refuse of any kind are burned, their carbon disappears as carbon dioxide, but not quite all. Some particles of carbon rise in the air and float away in the form of smoke. Hold a piece of glass over the flame of a candle and watch it become covered with black particles of solid carbon (soot). A volcanic eruption (see Chap. XXVI) fills the air for thousands of miles with microscopic dust. Many flowers discharge large quantities of microscopic pollen-dust into the air. Millions of meteors (see Chap. VI) enter the atmosphere every day, and, broken up by frictional combustion, become invisible dust. This extra-terrestrial dust has the special name of **cosmic dust.** The air-dust from various sources, but especially from coal consumption, accumulates in large towns to such an extent that the sun's rays are often effectually obscured. Its dangerous accumulation is, however, stopped by (1) its settling down by gravity, (2) showers of rain, which, by removing the dust, freshen and purify the air. Over the ocean there is generally less of this dust than over the land; over highlands there is generally less than over lowlands.

Exercises

1. From what sources is carbon dioxide passing into the air? How do you explain the fact that the average quantity of carbon dioxide in the air does not increase?
2. Why is it dangerous to remain near the mouth of a lime-kiln?
3. What is the difference between a compound and a mixture? What reasons are there for believing that the oxygen and nitrogen of the air are merely mixed together?
4. Describe four experiments: one to prove that air contains oxygen, a second that it contains nitrogen, another that it contains carbon dioxide, and a fourth that it contains water-vapour.
5. What are the chief sources of dust-motes in the air?

CHAPTER XII

Temperature and Pressure of Air

Source of Heat.—Bodies that allow light heat-rays to pass through them are called transparent, those that do not are called opaque. Bodies that allow dark heat-rays to pass through them are called diathermanous, and those that do not are called athermanous.* Bodies transparent to light are not necessarily diathermanous to heat. Water is transparent to light, but nearly athermanous to heat. The air is transparent to light radiation, and fairly diathermanous to heat radiation; glass is also transparent to light, but athermanous to heat. Light heat-rays, then, pass through the air without warming it. They are absorbed by the rocks and soil and water of the earth's surface, and then radiated as dark heat-rays. This radiated heat warms the air as it passes upwards from the lower to the higher atmosphere, and but for the water-vapour in the air would be lost in space. But from the sun there come, besides the light heat-rays, dark heat-rays which are absorbed by the water-vapour of the air. So that the water-vapour in the air assists in warming the air, both directly by absorbing dark radiation from the sun, and indirectly by preventing the too rapid loss of dark heat radiated from the earth (see p. 190). The air itself is mainly warmed indirectly from the sun by the dark heat-rays radiated from the earth, and in part by direct contact with the warm surface of the earth. The air heated by contact expands, rises, and mixes with the cooler air above, warming the upper air by convection. The air inside a glass-house is heated almost entirely by radiation. Luminous heat-rays from the sun pass through the air to the glass, which may be considered to act to the interior of the house as the screen of water-vapour does to the lower air above the earth, then through the glass to the floor of the house. There they are absorbed and radiated, as dark heat-rays, which, **because the glass is athermanous**, are kept imprisoned in the house and warm the air within. The land surface of the earth is a better absorber and a better radiator than the water surface, so that while the summer sun is shining, the air over all land surfaces is warmer than that over the water surfaces, and at night the air over water surfaces is warmer than that over the land surfaces. In winter the conditions are reversed. During the long days of summer in temperate latitudes the heat absorbed by the continental masses is far in excess of what is radiated during the short nights. So that, towards the end of summer there is a stored-up accumulation of heat which makes the end of summer hotter than the middle. The opposite process of chilling by radiation is even more marked towards the end of the long days of winter, especially over the land mass of the Eurasian continent, resulting in severely low temperatures in Eastern Siberia (see p. 213). All the light heat-rays that reach the land surface are not absorbed; some are reflected as light-rays, which may be absorbed and changed to heat by other bodies after reflection. Thus, since dark-coloured rocks and soils are good absorbers and radiators (see p. 23), the air itself over regions like the south-west of Russia and the Deccan of India is warmed by radiation of heat from the black soil.* But the air over light-coloured soils such as sandy deserts and chalky and limestone regions is not much warmed by radiation, because most of the solar light radiation is reflected from such surfaces as light. A person travelling in such a district in bright sunshine would be almost blinded by the reflected light, and if clothed in dark-coloured material would feel great heat, not so much from hot air as from the absorption by his clothes of radiated light, reflected from the light-coloured soil. Because of this difference between the radiation of dark heat and the reflection of light heat from the earth's surface, atmospheric temperatures should always be taken *in the shade*, so as to get the actual temperature of the air without complicating the result by the effect of reflected light-rays that might be absorbed by the thermometer itself.

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* The term *adiathermanous* is sometimes used as the opposite of diathermanous.

Effect of Latitude and Elevation.—Since the solar rays are nearly vertical within the tropics, that belt of the earth will obviously have the most heated atmosphere. Generally speaking, the atmosphere becomes cooler as we go farther from the Equator because of the diminishing angle of the solar rays. This is otherwise stated by saying that temperature varies with the latitude ; but, as we shall see, that is a very imperfect account of the conditions of varying temperatures. In fig. 22 the heating power of beam *A*, being more vertical, is much more concentrated than that of *B*. The same diagram shows the difference between the concentrated heat of noonday

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* This effect is apparent even though the dark-coloured soil be covered with vegetation.

(*A*) and the dispersed heat of evening (*B*). The difference between the temperature in equatorial regions and that at the poles is a case of *horizontal distribution.* There is also a *vertical distribution.* The layers of the atmosphere nearest the earth are naturally the warmest for three reasons. *Firstly,* because the lowest layers are in nearest contact with the warming surface of the earth, and so have a source of warmth that the upper layers benefit by only through the convection of this heat. *Secondly,* on high mountains a traveller being nearer to the sun receives the light heat-radiations from the sun more intensely than he would down in the valley. He gets more easily sunburnt there, and photographic plates require less exposure there. In spite of this, however, the *air* in these upper regions is colder than down in the valley; for the air at a height being rarer and lighter allows a more rapid loss of radiated dark heat-rays (see p. 23). The air there, for the same reason of rarity, contains less water-vapour; therefore less of the dark solar rays are *directly* absorbed, and there is less screen-checking of heat-rays escaping from the earth. The air in a plain on the Equator side of a high mountain range, such as the Indo-Gangetic plain south of the Himalayas, is warmer than it would be away from the mountain range; partly because it receives from the mountains some reflected solar light-rays in addition to those received directly from the sun, and partly because the mountains check slightly the radiation of heat from the plain. *Thirdly,* when air rises, it expands, and its latent heat being used up in the expansion, it cools as it expands. So, for these *three* reasons, upper layers of the atmosphere are always cooler than the lower. This is spoken of as the *vertical distribution of temperature.* Thus, when the temperature of the air in the plain of Lombardy is 75° F., at the top of Mont Blanc it will be as low as 25° F.

The Thermometer.—The temperature of the air at any place depends upon the latitude of the place, its altitude, its situation with respect to adjacent high land, the season of the year, and the time of day. To measure the variations in the temperature of the air (or of any gas or liquid), an instrument called a thermometer is used. Temperatures are marked by the height of the mercury or alcohol, which rises by expansion with an increase of temperature and falls by contraction with a decrease. Where the liquid stands when the instrument is placed in ice and water is called **freezing-point**; where the liquid stands when the instrument is placed in the steam from boiling water is called **boiling-point.** If the freezing-point is marked 32° (32 degrees) and the boiling-point 212°, the instrument is called a *Fahrenheit* thermometer; if the two points are marked 0° and 100°

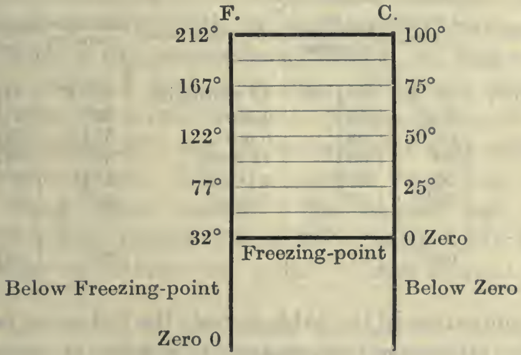

FIG. 39.

For conversion without a table, remember that every 9° F. = 5° C. To convert F. to C., subtract 32° and multiply by $\frac{5}{9}$; to convert C. to F., multiply by $\frac{9}{5}$ and add 32°.

respectively, the instrument is called a *Centigrade* thermometer.* It is important always to state the kind of thermometer used for making observations. For converting Fahrenheit to Centigrade, a simple table (see previous page) should be prepared and kept for reference.

Range of Temperature.—The highest temperature reached during any day is called the *maximum* temperature for that day; the lowest temperature reached is called the *minimum* temperature. The difference between the two is called the **daily range.** The difference between the maximum summer and the minimum winter temperatures is called the **annual range.** Half the sum of the maximum and minimum temperatures gives the **daily mean** or the **annual mean.** The mean for any period (say a month) can be found by taking the average of the daily means of the period. Temperatures taken on the Eiffel Tower at different heights give the following summer and winter averages:

July mean	at 2 metres elevation	at 302 metres elevation.	December mean	at 2 metres elevation	at 302 metres elevation.
12 midnight	58° F.	59¼° F.	12 midnight	34° F.	34½° F.
4 a.m.	55½°	57½°	4 a.m.	33°	34°
8 a.m.	63¼°	58¼°	8 a.m.	32¾°	33½°
12 noon	70°	63½°	12 noon	38°	35¼°
4 p.m.	70°	65½°	4 p.m.	37½°	35½°
8 p.m.	63½°	62°	8 p.m.	35°	35°
Mean	63½°	61°		35°	34¾°

An examination of the table reveals the following facts:

(*a*) The minimum temperature is always at sunrise.

(*b*) The maximum at the upper station is two hours later than at the lower. (The maximum at the lower station occurred at 2 p.m., and is not shown in the table.)

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* Boiling-point varies with the barometric pressure. 100° C. is defined as the boiling-point of water at a pressure of 76 cm.

(*c*) Rise of temperature begins at the surface of earth and takes two hours to rise 1,000 feet.

(*d*) The upper station temperature is never so high as that of the lower.

(*e*) The upper station temperature is never so low as that of the lower.

(*f*) The maximum temperature is never exactly at noon.

Many other interesting and useful facts may easily be gathered by studying the figures of the table. Those given will serve as a guide to inquirers.

Daily range on land is much greater than at sea; and not only that, but the air over land is warmer in summer and colder in winter than the air over sea in the same latitudes. Hence, as we shall find later, the temperature of places far inland has a much greater range than the temperature of islands or continental borders. On land the range increases with the dryness of the atmosphere, since with a dry atmosphere there is an easier escape for the radiated dark heat-rays. Over the sea in the torrid zone the annual range is commonly less than 10°, and less than 20° over the majority of seas within the temperate zones. But the annual range on land is very much more marked. The Sahara and Central Australia have ranges of over 30°; in the United States the range varies from 30° to 60° *; over most of Europe and Asia it passes 40°, and in North-eastern Siberia the annual range exceeds 100°. If the annual range is great the climate of a place is called extreme; if the range is small the climate is called equable.

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* This variation in temperature is graphically illustrated by the remark that the best costume for San Francisco is a linen coat with a fur collar. In Washington, on the east, the glass has been known to fall 30° in one hour. The observer states that it was "hot summer when he left the house; it was near freezing-point when he returned within the hour."

Maximum and Minimum Thermometers.—These are instruments that record automatically the maximum and minimum temperatures for the period (usually a day) between one setting and the next. Both instruments are set horizontally. In the maximum thermometer there is introduced into the stem before sealing, above the mercury, a small piece of iron wire with beaded ends, which works loosely in the tube. When the mercury expands it pushes this wire marker before it, and on contracting leaves it at the highest place to which it has been pushed. The reading at the end of the marker nearest the mercury is the maximum temperature for the period. The instrument is reset by drawing the marker back to the mercury with a magnet. The minimum thermometer contains coloured alcohol instead of mercury, and a beaded glass marker within the liquid instead of outside. When temperature falls, the marker is dragged back by the surface tension of the alcohol. When temperature rises, the marker remains stationary while the alcohol flows past, leaving the marker at the lowest point to which it has been dragged. The end of the marker farthest from the bulb gives the reading of the minimum temperature reached. The instrument is re-set by shaking the marker up the stem to the end of the alcohol column.

Pressure of Air.—Air has weight and presses down upon the earth. If it were solid it would press only downwards; but being a gas it exerts its pressure in all directions. The upward pressure may be shown in the following way. Fill a smooth-edged tumbler full to the brim with water, and place over the mouth a sheet of smooth, strong paper. Hold the tumbler in the left hand, and keeping the paper in its place with the right, invert the tumbler and then remove the right hand from the paper. It will be seen that the paper remains in position, and that the water does not fall out. This is because the air presses upwards against the outside of the paper. If you have an air-pump, you can prove in another way that air exerts pressure. Fill a bladder with air and place it under the bell-jar of the air-pump. Exhaust the bell-jar, and the bladder will be seen to expand and possibly to burst. That is to say, if you remove the pressure from outside the bladder, the pressure from within has a chance to show itself.

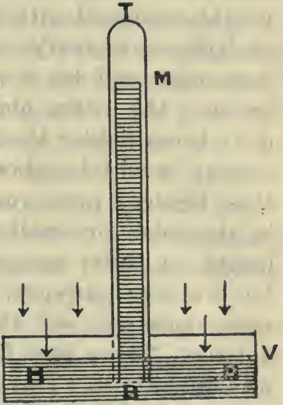

FIG. 40.

The Barometer.—The pressure of the air can be measured by an instrument called the **barometer** (fig. 40). The diagram explains the principle upon which these instruments are constructed. The tube *TB* is closed at the end *T* and filled with mercury. It is then turned upside-down in the vessel *V*, containing mercury *H*. The thumb must be pressed to the open end of the tube and not be removed till it is under the mercury in the trough. The mercury does not flow out of the tube into the vessel. This is because the mercury in the vessel is pressed against the mouth of the tube by the column of air above the mercury in the vessel as shown by the arrows. Hence the height of the mercury in the tube will depend upon how heavily the air presses down upon the mercury in the vessel. In other words, the height of the mercury in the tube in inches is a means of estimating the pressure of the atmosphere. Thirty inches of mercury in the tube is the average height at sea-level. Other liquid substances besides mercury could be used for the barometer. But mercury is the most convenient, because of its great weight compared with other liquids. Water is 13½ times as light as mercury. Therefore, if the pressure of air were measured by a water column, this column would be 30 × 13½ inches high, *i.e.* about 34 feet. Glycerine is 11 times lighter than mercury. Therefore a glycerine column would be about 27 feet high. Hence, though these lighter liquids would show a great alteration of level in the tube for small variations of pressure, the great length of tube necessary renders them inconvenient for ordinary purposes. Furthermore, mercury is easily seen, does not wet the glass, and is practically non-volatile. There is a form of barometer which contains no liquid at all. This is called "aneroid," a word which means "*not wet.*" It consists of a thin metal air-tight box or case, nearly exhausted of air. As the pressure of the air outside the case increases, the lid of the case is depressed, because there is not sufficient air inside to withstand the increased pressure outside. When the outside pressure decreases, the lid being elastic regains its former position. This movement of the lid is communicated by levers to a dial-hand, which thus registers the air-pressure on a graduated dial. The aneroid barometer is the one used in determining heights, because it is easily carried.

Difference of Pressure.—The pressure of the air can be measured in pounds and ounces avoirdupois. A cubic foot of air at sea-level weighs about 1¼ oz., and at sea-level the pressure of a vertical column of air 1 square inch in cross-section is 14·7 lb. There is this pressure upon every part of our bodies, nearly 15 lb. upon every square inch of our outer surface, compensated, however, by the same pressure from within, outwards. If you go rapidly down a coal-mine you will find that the pressure of the air has become greater than it was at the surface, and until you have breathed in enough of this high-pressure air to give you the same pressure inside you as you have outside you, the drum of your ear will seem likely to burst inwards. At sea-level, when the barometer stands at less than 29·7 inches we speak of the pressure as being *low*; if it stands at over 30 inches we say the pressure is *high*. 29·9 inches is considered a typical mean pressure, and the isobar (see p. 146) of that pressure is called the "normal." The three chief **causes of variations in pressure** are (*a*) **temperature,** (*b*) **water-vapour,** and (*c*) **change of altitude.**

(*a*) **Air-pressure and Temperature.**—Air, like other forms of matter, expands and becomes lighter with increase of temperature; it contracts and becomes heavier with a decrease of temperature. Therefore, as air becomes warmer, the pressure is lessened and the barometer falls. In the northern summer Central Asia (see p. 156) is greatly heated by solar radiation and the atmospheric pressure there is lowered during the hot months of the year from an average of 30·5 to one of 29·5 inches.

(*b*) **Air-pressure and Water-vapour.**—Moist air is lighter than dry air; in fact, in any given volume of air saturated with moisture, at, say, 50° F., the air without the water-vapour would weigh over 100 times the weight of the water-vapour present in that air. It may be a little difficult at first to understand why air should be lighter when something (moisture) is added to it. Note, however, that the density of air compared with that of hydrogen (the standard of density for gases) is as 14·5 to 1. But water-vapour has a density of 9. That is, being composed of two molecules of hydrogen and one of oxygen, and oxygen being 16 times as dense as hydrogen, its density is $\frac{(2 \times 1) + (16 \times 1)}{2} = 9$. Therefore the density of dry air compared with that of water-vapour is as 14·5 is to 9. Hence, the addition of water-vapour to the air, by lessening the density, lessens the pressure of the air, and the larger the proportion of water-vapour in the air the more will the pressure be diminished. The daily local variations of pressure due to the variations of the quantity of water-vapour in the air are more frequent than those due to variations of temperature, especially in the coastal regions of the world; but the seasonal continental variations, such as the movement of the low-pressure area from South Africa during the southern summer to North-east Africa during the northern summer, are mainly thermal. Although the presence of water-vapour in the air depends upon the process of evaporation, which again is regulated by temperature, it is necessary to keep distinct the changes of pressure due to thermal changes only, and those due to distribution of water-vapour depending upon thermal changes.

(*c*) **Air-pressure and Altitude.**—The higher we go above sea-level, the less is the pressure of the atmosphere, just for the same reason that the hay at the top of a stack is less tightly pressed together than the hay at the bottom. Therefore, a low barometer may indicate either very warm air, or very moist air, or a certain height above sea-level. The pressure of the air is 1 inch less for every 960 feet of ascent, but not constantly so. Aneroid barometers are sometimes marked to show how heights vary with differing pressures. There is a difference of 3·72 inches between the pressure at the bottom and that at the top of Snowdon; and if you could reach the top of Mont Blanc, you would expect to find the barometer fall to about 15 inches.

The Millibar.—In order that there may be a system of registering atmospheric pressure measurements common to all nations, the meteorological authorities early in 1914 brought into operation a new terminology and a new scale, the unit of which is a millibar. The millibar is the equivalent of ·02953 inches of pressure, so that 1,000 millibars are equal to 29·53 inches. On maps of pressure systems the isobars may now be marked in centibars and decimal fractions of a centibar. Thus, 1,016 millibars of pressure would be marked as the isobar of 101·6 centibars, and so on. The new unit may be read into the old weather-glasses from the following table:

29·00 in. = 982·0 millibars = 98.2 centibars = stormy
29·50 ,, = 999·0 ,, = 99·9 ,, = wet
30·00 ,, = 1015·9 ,, = 101·59 ,, = fair
30·50 ,, = 1032·8 ,, = 103·28 ,, = set fair

Rainfall will, when the new system is thoroughly established, be measured by millimetres at the rate of 25·4 to the inch. Wind velocity will be measured by metres per second, and 22·4 metres per second will be the equivalent of 50 miles per hour.

Exercises

1. Describe the principle of the barometer. What would be the effect on its height of (*a*) slightly tilting it sideways; (*b*) increased moisture of the

air; (*c*) increased warmth of the air? (Oxf. Loc. Jun.)

2. Describe the arrangements which are made for observing the temperature of the air. At what time of day are the readings of the thermometer usually taken? (Oxf. and Camb. Lower Cert.)
3. Explain why changes of weather in this country are usually accompanied by a rise or fall of the barometer. (Oxf. and Camb. Lower Cert.)
4. What are the uses of a barometer? Make a sketch of the instrument and explain how it works.
5. What is meant by *mean annual temperature*? How is it determined from observations? Mention any place you know of which has a mean annual temperature of about 40° F. (Oxf. Loc. Jun.)
6. Why is it necessary to correct the readings of a barometer for the height of the place above sea-level? (See p. 146.)
7. Explain the chief causes which determine the distribution of temperature in the atmosphere. How do you account for the low temperature in the higher regions of the atmosphere?
8. How is the heat of the sun imparted to the atmosphere?
9. Why is mercury the liquid usually employed in the construction of barometers and thermometers?
10. How can it be proved that air has weight?
11. What is meant by the *pressure of the atmosphere*? Explain the effect of (1) heat and (2) water-vapour on atmospheric pressure.
12. What are the principal causes of the variations in the pressure of the air at any one place, and why do they produce such variations? (Camb. Loc. Sen.)

13. Give an account of the annual variation of temperature at different points on the latitude of Greenwich. (Oxf. and Camb. Sch. Cert.)

14. Four similar thermometers are placed as follows: No. 1 on grass; No. 2 above ground, screened, but with free access to the air; No. 3 above ground unscreened; No. 4 on a wall facing south-west.

    How would you expect their readings taken (*a*) shortly after sunset; (*b*) at noon, the sky being cloudless, to differ? Account for the differences in the readings. (Oxf. Loc. Jun.)

15. Write an essay on the following subject:

    The relation between the distribution of temperature and the distribution of atmospheric pressure over the earth's surface. (Civil Service.)

CHAPTER XIII

Winds

Barometric Gradient.—If upon a map a number of stations are indicated and the height of the barometer at each station at a certain time marked against each station, it would be possible to draw lines joining all those stations that had the same pressure. These lines are called **isobars.** In such a case, the pressures, before being placed on the map, are corrected to sea-level, *i.e.* if a station were on a hill 960 feet high, one inch would be added to the reading at that station before marking it on the map. Now, just as water flows from a high level to a low level, so air moves from a place where pressure is high towards a place where pressure is low. Just as the velocity of the flow of water is greater in proportion as the gradient or slope down which it flows is steeper; so the greater is the speed of the moving air, the greater the difference between the high pressure and the low. The moving air is called **wind,** and when the adjacent isobars are drawn close to each other, then the steeper is the pressure-gradient and the harder we say the wind blows. Thus, in fig. 41, the winds blowing in the region marked *B* are gentler than those blowing in the region marked *C*, and these again, gentler than those blowing at *A*. When the isobars on the map are

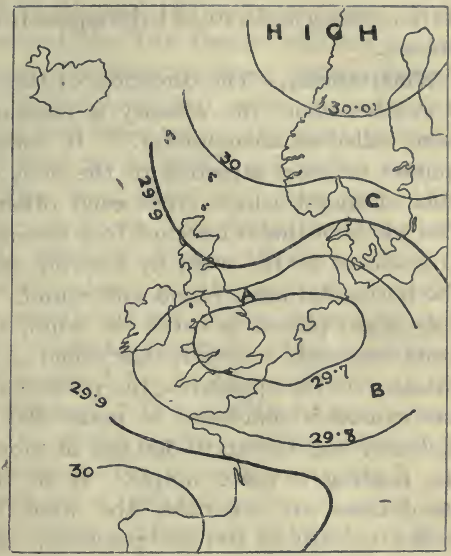

FIG. 41.

wide apart, the gradient may be described as gentle or moderate; when they are close together, the gradient is said to be steep. The gradient is calculated thus: Measure the distance in miles from isobar to isobar along a line square to both isobars; note the difference between the readings of the two isobars; then, according to the difference of pressure for x miles, find the difference in hundredths of an inch for every 17 miles (17 statute miles = 15 nautical miles). For example, two isobars with a difference of ·2 lie squarely 104 miles apart. This is equivalent to $\frac{3}{100}$ of an inch for 17 miles. Consequently we say that the gradient is 3. Any gradient up to 1 is moderate; a gradient of 2 may be called steep and would mean a wind velocity approaching 40 miles per hour; a gradient of 15, which corresponds to a pressure-difference of ·6 in one degree of latitude, would mean a hurricane. The **barometric gradient** may therefore be defined as the difference between two atmospheric pressures expressed in hundredths of an inch per 17 miles, the two pressure-stations being understood to lie squarely on their respective isobars.

Wind-velocity.—The direction of the wind is shown by a weather-vane, the velocity is measured by an instrument called an anemometer. * It consists of four hemispheres or cups attached to the ends of two horizontal rods of metal which cross each other at right angles. The whole of this is fastened to a vertical axis which spins in a socket as the wind by blowing into the cups sends the horizontal arms round and round. The cups revolve only when placed to catch the wind, and the horizontal arms are such a length that when a mile of wind has passed over the apparatus, the vertical axis by its spinning has caused a dial-hand to make 500 revolutions. The dial may register up to 500,000 or more revolutions, and the reading is quite simple. If in three hours 15,000 revolutions are recorded, the wind has been blowing with a velocity of 10 miles per hour. The velocity of the wind is usually greatest at mid-day and least during the night. On mountains, however, the velocity is least in the day and the direction uphill; at night the velocity is greatest and the direction downhill. During gales the wind attains a high velocity, even as much as 80 miles an hour. At Pendennis Castle, Falmouth, on one occasion, the anemometer recorded a gust at the rate of 103 miles an hour. Some anemometers record the wind-pressure as well as the wind-velocity. Wind-pressure is quite different from air-pressure; the former is a lateral pressure, the latter is understood as vertical, though really exerted in all directions. A wind having a velocity of 5 miles per hour presses laterally with a force of about 2 oz. per square foot, 20 miles per hour 2 lb., 40 miles per hour 8 lb., 60 miles per hour 18 lb.,

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* Greek *anemos*, wind; *metron*, a measure.

80 miles per hour 32 lb., and 100 miles per hour 50 lb. The wind that caused the Tay Bridge disaster in December 1879 averaged 70 miles per hour with a pressure of 24 lb. to the square foot, and some gusts in that storm had a velocity of from 100 to 150 miles per hour with a pressure of from 50 to 112 lb. per square foot.

Ferrel's Law.—The wind, however, does not blow straight down the gradient; nor, indeed, does water ever flow straight down a slope. At the surface of the earth there is a tendency on the part of all easily-moving bodies, especially air and water, to be deflected, as they move, in a constant direction. This generalisation was first propounded by Professor Ferrel, of the United States, as follows: "The deflecting force exerted on the winds of the globe by the earth's rotation is inversely proportionate to the velocity of motion." As the velocity of rotation is greatest at the equator, the amount of constant deflection there will be least. That is, the deflecting force is zero at the equator and at its maximum at the poles. In the northern hemisphere winds are deflected to the right, looking in the direction towards which the wind is blowing, *i.e.* clockwise; in the southern hemisphere to the left, *i.e.* counter-clockwise. At (*a*) (fig. 42) the arrows show the direction that would be taken by winds if it were not for the rotation of the earth, at (*b*) the arrows show the direction actually taken by the winds in the northern hemisphere. The statement of this uniformity of deflection is called **Ferrel's Law.** While currents are named by the direction towards which they flow, winds are named by the direction *from* which they blow. A land breeze is a breeze blowing from the land, or a north wind is one blowing from the north.

Ballot's Law.—Dr. Buys Ballot, a Dutch meteorologist, made the following valuable generalisation : "It is a fact above all doubt that the wind that comes is *nearly* * at

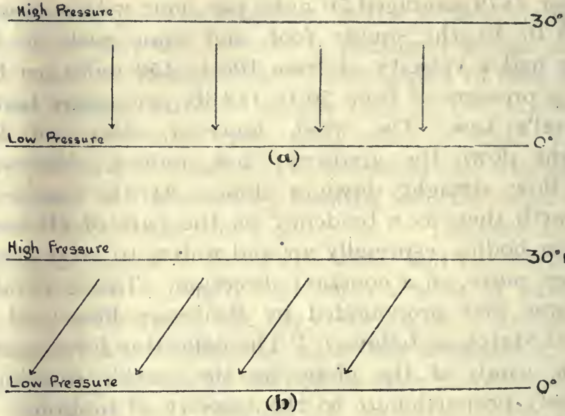

FIG. 42.

right angles to the line between the places of highest and lowest barometer readings. The wind has the place of lowest barometer at its left hand, and is stronger in proportion as the difference in barometer readings is greater." Various subsequent writers, attempting to simplify this statement, have given it as : "Stand with your back to the wind, and the barometer will be lower on your left hand than on your right," or, "When you face the wind, the centre of depression bears in the right-hand direction." Ballot's law states the fact of which the barometric gradient is the explanation. Combining Ferrel's law with Ballot's, we get the following new generalisations.

In the diagram (fig. 43) the gradient is from W. to E., but by Ferrel's law the wind is deflected from the W. to the N.W., and instead of travelling due E., it travels S.E. Hence :

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* The italics are the authors'.

The wind is *northerly* when barometer is high in W. and low in E.

The wind is *southerly* when barometer is high in E. and low in W.

The wind is *easterly* when barometer is high in N. and low in S.

The wind is *westerly* when barometer is high in S. and low in N.

For example, on March 3, 1909, the barometer was 29·2 in London at 7 a.m., and in Hull at the same time it was 29·3. At Ipswich and at Yarmouth a S.E. wind was then blowing, and at Derby an E. wind. On the next day at 7 a.m., the barometer in London was 29·3, in Birmingham 29·4, and in Waterford 29·5. A north wind was then blowing over the whole of the British Isles, except the north of Ireland, where a N.E. wind blew, and Berwick, where a N.W. wind blew. Next day at

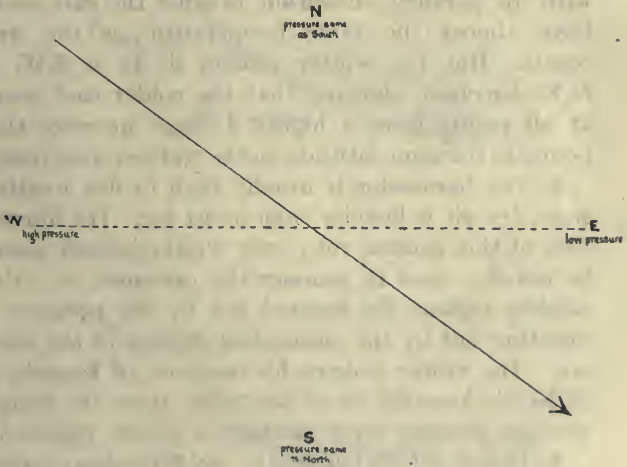


Fig. 43.

7 a.m. the barometer was 29·6 all along the south coast of England and 29·5 at the foot of the Cheviots. A west wind was then blowing over the whole of England and Wales except in Cardigan Bay, where it blew from the S.W.

Changes in the Barometer.—The words "Fair," "Change," etc., often found on barometers, are of very little value, and it is really a mistake to regard the barometer as a "weather-glass." The condition of the barometer at any one place can tell us very little about the weather. Reliable forecasts require the comparison of readings from many places. The following summary may help in interpreting the local barometer:

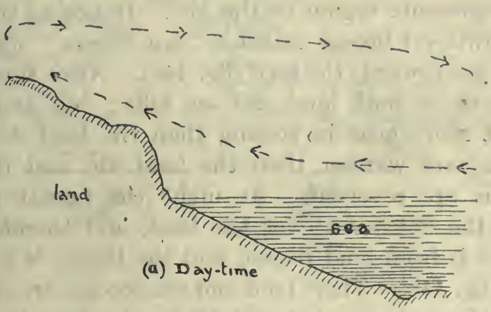
1. The barometer is usually high in cold weather, since cold air is heavier than warm air. Thus the summer isobars of the British Isles nearly coincide with the parallels of latitude because the east coasts have almost the same temperature as the west coasts. But the winter isobars lie in a S.W. to N.E. direction, showing that the colder east coasts at all points have a higher average pressure than points in the same latitude on the warmer west coasts.

2. The barometer is usually high in dry weather, since dry air is heavier than moist air. [In illustration of this general rule, only winter isobars should be noted; since in summer the pressures over dry, rainless regions are lowered not by the presence of moisture but by the diminished density of the warm air. The winter isobars, for instance, of Eurasia, or of North America, or of Australia, show the highest average pressure over rainless or desert regions.]

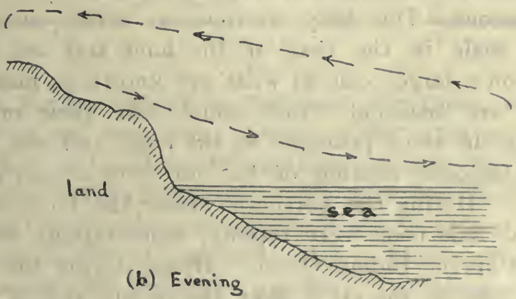
3. Hence, a high barometer, say 30 inches or more, indicates (*a*) that it is too cold for rain or too dry; (*b*) that the wind, if any, is blowing, over Europe, from a cold or a dry quarter, *e.g.* N.E.

4. So, a low barometer in western Europe indicates the arrival of moisture-laden winds, *e.g.* S.W. If very low, it indicates that the air is both warm and moist, and heavy showers will fall.

Land and Sea Breezes.—Inequalities of temperature are the chief cause of differences of atmospheric pressure. On an ordinary sunny day solar rays fall equally on the sea and the land. But owing to the greater specific heat of water the temperature of the sea rises more slowly than that of the land (see Chap. III). The temperature



(a) Day-time



(b) Evening

Fig. 44.

of the air (except where hot winds blow in from other regions) depends upon the temperature of the land or sea beneath it. Hence during the day the air over the land becomes warmer than that over the sea, and so expands more and rises. This is called an "upcast" of the air over the land. To take the place of the air rising up from the land there is an indraught of air from the sea. Or to put it another way, the expanding, rising air over the land is at low pressure, the cooler air over the sea is at high pressure, and the flow must be from the high-pressure region to the low. Hence in the daytime a low-level breeze called a "sea breeze" will blow from the sea towards the land (fig. 44a). After sunset the temperature of both land and sea falls; but as the sea gives out more heat in cooling than the land does, the sea air is now warmer than the land air, and the day conditions are reversed. At night the upcast is over the sea, the downcast over the land, and therefore the indraught is from land to sea, and the breeze is a "land breeze" (fig. 44b). These land and sea breezes are only felt strongly along the coast itself. Ten miles from the coast, either out at sea or inland, they cease to be perceptible. They are most marked in tropical regions.

Monsoons.—The daily alternations which occur on a small scale in the case of the land and sea breezes occur on a large scale in what are known as **monsoons.*** These are seasonal winds which owe their origin to exactly the same principle as the land and sea breezes —the unequal heating of the air over continents and oceans. During the northern winter the land mass of Central Asia cools very rapidly, more rapidly than the waters of the Indian Ocean. Hence during this season the upcast of the air is over the ocean, and dry winds blow from the land seawards, deflected according to Ferrel's law westwards. This wind, blowing from October to May from the north-east towards the south-west, is known as the **north-east monsoon** (fig. 45). This monsoon, gathering up moisture as it crosses the Bay of Bengal, brings rain to the south-eastern coast of India and to Ceylon—which is fortunate for these regions, since they are very little helped by the other monsoon. From May to October, the northern summer, the upcast of heated air is over Central Asia ; therefore there is an indraught of moisture-laden air from the ocean to the continent, deflected eastwards, and so blowing from the south-west to the north-east (fig. 45A). This, the **south-west monsoon**, brings heavy rains to India (especially on the

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* From the Malay word *músim*, a time or season.

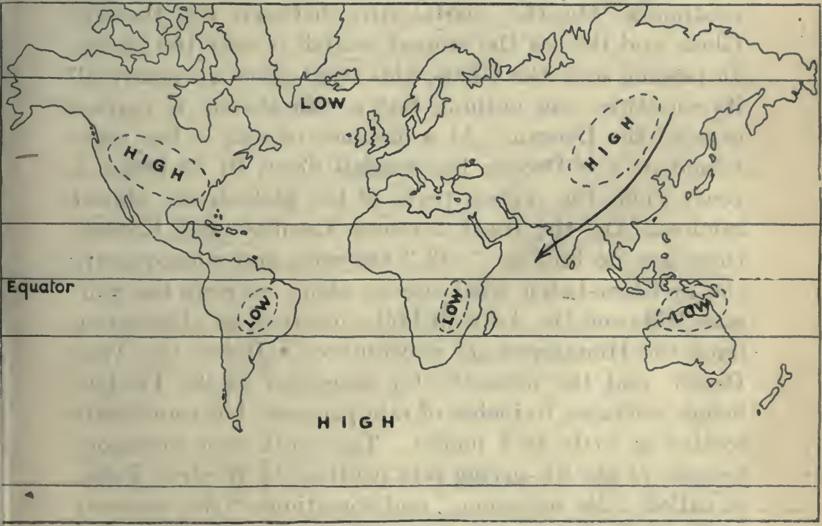


Fig. 45.

western coast) and to parts of eastern Asia. Assam is said to average nearly 2 inches of rainfall per day. The burst of the south-west monsoon in India at the end of May takes place in a succession of tremendous thunderstorms, and so violent is the south-west wind that it actually closes the harbours of the west coast. During June, July, August, and September the rainy season continues. On the coastal strip between the Western Ghats and the sea the annual rainfall is over 100 inches. In passing over the Ghats, this wind gives up nearly all its moisture, and nothing but a *rain-shadow* is carried over to the Deccan. At a distance of only a few miles inland on the Deccan the rainfall drops to 25 inches a year, while the central parts of the plateau are almost rainless. On the coast between Cambay and Karachi there are no hills to " call " the rain, and consequently the moisture-laden wind sweeps along between the Suliman Hills and the Aravalli Hills, meeting no obstruction until the Himalayas are encountered. Hence the Thar Desert, and the necessity for irrigation in the Punjab. Scinde averages 10 inches of rain per year, but some parts receive as little as 3 inches. The south-west monsoon, because of the life-giving rain it brings to Western India, is called " *the* monsoon," and sometimes " the summer monsoon." It blows from the equator north-eastwards, and is strong enough to counteract completely the north-east trades that blow in all other parts of the northern tropics. The winter monsoon is really the north-east trade wind, and this blowing across the Bay of Bengal picks up sufficient moisture to bring light rains to the eastern coast, to the South Deccan, and to Ceylon. So that the South Deccan and Ceylon benefit by both monsoons; North-west India benefits by the south-west monsoon only, and very little even from that. Monsoon conditions are also well developed in Australia, for in summer the south-east trades bring rain to the north and the east coasts; in winter they blow off the land. The Gulf of Mexico also has its monsoonal seasons.

Permanent Winds.—Permanent winds are produced in precisely the same way as the land and sea breezes and the monsoons. The difference is that in the latter cases the high- and low-pressure regions change places seasonally or periodically; while in the former the high- and low-pressure regions are permanent, because they are due to the permanent differences in temperature between the equatorial and other zonal regions. The earth is divided into zones: there is a cold or frigid zone about the poles, and a hot or torrid belt at the equator. Therefore the equator will be a region of low pres-

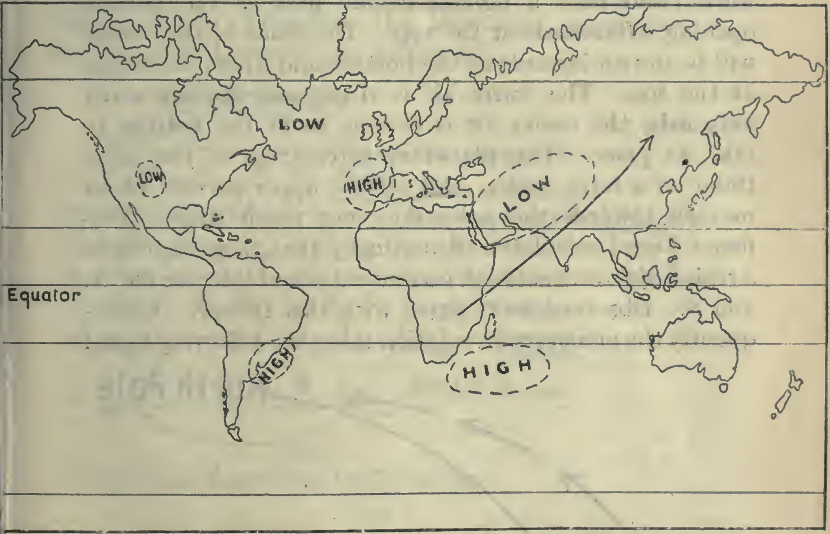


FIG. 45A.

sure, and the poles regions of high pressure. Hence there will be a steady flow of air from polar parts towards the equator to take the place of the air expanding and rising there. This movement of the air is called the **planetary circulation.** Open the window slightly at both top and bottom when the room is fairly warm, and hold a lighted candle first at the bottom opening, afterwards at the top. The flame of the candle will be drawn inwards at the bottom and drawn outwards at the top. The warm air is rising and moving away outwards, the cooler air is coming in at the bottom to take its place. The planetary circulation is the same thing on a large scale. But all the upper current of air moving towards the poles does not reach there. Professor Ferrel calculated theoretically that there should be a region of down-cast high pressure at about latitude 30° N. and S. Observed facts agree with this theory. Consequently the planetary circulation takes the following form:

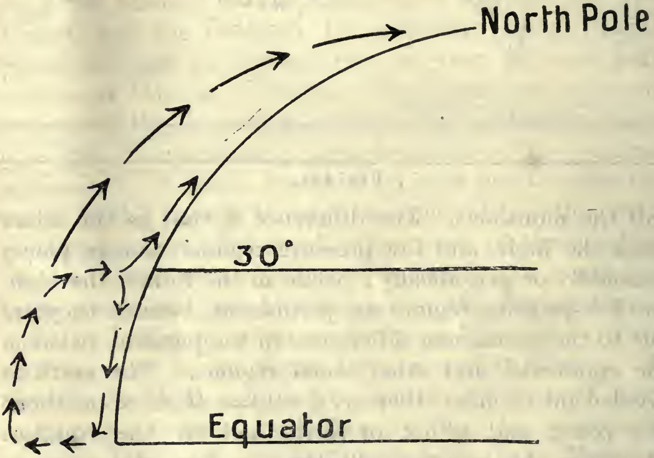
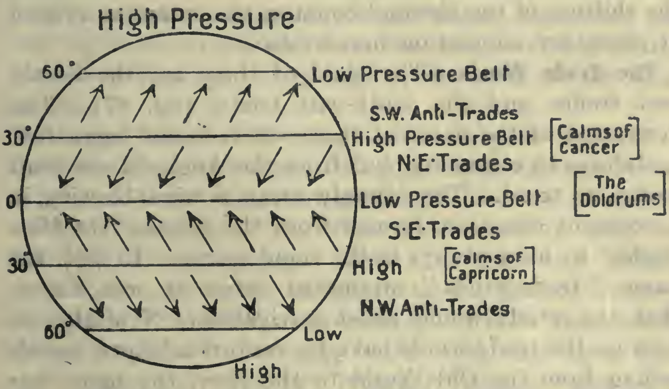


FIG. 46.

From 30° N. towards the equator blow the north-east trades (westward deflection due to rotation); at 30° N. occurs a high-pressure belt of calms (Calms of Cancer); from 30° N. to 60° N. blow the south-westerlies (eastward deflection due to rotation); at the equator there is a low-pressure belt of calms (Doldrums). The southern hemisphere corresponds (with opposite deflection) to the northern. Therefore the *theoretical* circulation of the permanent winds is as in fig. 47.



Theoretical Diagram of Air-Circulation

FIG. 47.

It will be seen from fig. 46 that in the upper regions of the air a wind is blowing in a direction opposite to that of the air near the south. These reverse winds blow at such a height that it is only on the tops of the highest mountains that they can be felt. Their direction, however, can usually be recognised quite easily by the constant drift of the highest clouds, and it has also been determined by the way volcanic dust was carried in certain notable volcanic eruptions. From the Krakatoa eruption (see p. 380) in 1883 the larger dust was carried in the direction of the trade wind, *i.e.* westwards; but the finer dust was carried through the upper air-strata eastwards, large quantities coming down at Timor, 1,200 miles to the east. The zones of calms are not quite constant in position, because the **thermal equator**, *i.e.* the line of maximum tropical temperature, lies slightly north of the geographical equator during the northern summer, and slightly south during the southern summer. With the shifting of the thermal equator, the complete system of planetary circulation moves also.

The Trade Winds.—The chief of these are the north-east trades and the south-east trades (fig. 47). The derivation of the name of these winds is not from their usefulness to commerce, but from the Anglo-Saxon word *tredan*, to tread. They simply mean a wind blowing in a constant direction, formed from the phrase "to blow trade," to blow always in the same course. In fact, the name "trade-winds" originated before it was known that the winds would assist navigation. Nevertheless, because the trade-winds have for centuries helped vessels sailing from the Old World to the New, the name has become so associated with the idea of commerce, that it is now difficult to divorce it. The equatorial belt of calms —the Doldrums—is about 15° wide, and from this to about 30° north and south the trade-winds prevail. The south-east trades, because of the smaller amount of land interference, are rather more constant and well-defined than the north-east trades. In both cases the velocity of the wind is from 15 to 20 miles per hour, and sailing vessels travel with ease in these winds 150 miles a day. In the northern hemisphere, sailing vessels returning from the New World to the Old make use of the south-west anti-trades or return trades. In the southern hemisphere the north-west anti-trades are the return winds for the eastward journey. The north-west anti-trades are very regular and strong; they blow rather more west than north-west, and so they are known as the "Brave West Winds." The belt of ocean between 40° and 50° south latitude is called the "Roaring Forties." Except for the toe of South America, no land interferes with the steady blowing of the Brave West Winds, and sailing vessels can start from, say, Cape Town, travel to New Zealand and back round the other side of the world, carried all the way by these winds, and beat the steamers that return from New Zealand to the Cape in the teeth of the west winds.

Pressure Systems.—It is generally a surprise to discover that weather forecasting is not done at the Royal Observatory at Greenwich, but at the Meteorological Office, South Kensington. This office was started in 1855 by Admiral Robert Fitzroy. Since that time vast strides have been made in the knowledge of the laws of weather changes, *e.g.* the old star-forecasting has been abandoned. So systematically and easily is the work done now, that anyone may telegraph to "Weather, London," and for a small sum obtain a forecast of nine days' weather in any neighbourhood, or a detailed statement as to the condition of the sea in the Irish Sea, the North Sea, or the English Channel. In the forecasting room at the Meteorological Office there are no instruments (beyond one barometer); but instead, there is an immense number of maps, each as large as the page of a newspaper, showing various portions of Western Europe and of the Eastern Atlantic. By international arrangement, observations of the wind, barometer, and thermometer are taken at a large number of stations every day at fixed hours, and the different countries exchange their observations. In the British

Isles there are thirty stations at which observations are taken at 7 a.m every day; these are telegraphed to London, where they are all received before 8 a.m. The messages are in numeric code, a string of figures (about 15) conveying quantities of information concerning the atmospheric conditions at each station. Wireless messages from the Atlantic are in the same form, except that a few extra figures are required to indicate the latitude and longitude of the dispatching boat. By 9 o'clock all the information is received, de-coded, charted, and isobars are then drawn through all points having equal barometer readings. These isobars always form some perfectly symmetrical arrangement, and all the possible arrangements or systems have been classified and named. The forecaster, having mapped the complete system of pressures, winds, and temperatures, has now a sort of picture of what is happening in the air all around. And as he has also a succession of similar maps giving the situations at various hours on previous days, he has a clue to the direction in which the different **pressure systems** are moving and what type of weather is accompanying them. It is quite possible that future forecasters will, by obtaining observations at great heights in the upper air, be able to produce predictions that are perfectly accurate and undeviatingly certain. The pressure systems (that is, the groupings of isobars) are not always the same in form

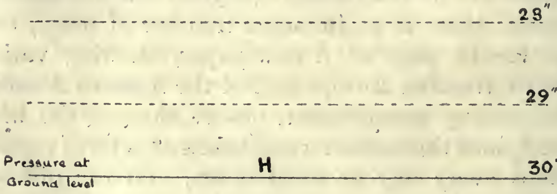


FIG. 48.

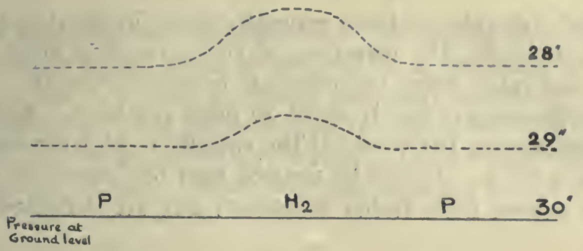


FIG. 49.

the chief forms are the **cyclone,** the **anticyclone, the wedge,** and the **secondary.**

The Cyclone.—Suppose a part of the earth at *H* (fig. 48) heated more than another or more saturated with water-vapour. Then the layers of pressure varying with different heights no longer remain horizontal but assume the form above H_2 in fig. 49. This leads to decrease of pressure at H_2 and to increase of pressure at *P*. Thus there arises a low-pressure region surrounded by a region of high pressure, with the winds consequently blowing from the outside inwards. This system is the **cyclone.*** It may cover a region anything from 100 miles to 3,000 miles across; a common diameter for a cyclonic system being 1,000 miles. The centre of the system is the geometric centre of the innermost isobar. The intensity of the cyclone is measured by the barometric gradient from the high pressure outside to the low pressure inside. The **path** of any system is the route followed by its central point; it is the same line as what is called the storm-track, the central point being the storm-centre. In the

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* It must be remembered that the name "cyclone" is sometimes used in the more limited sense of "whirlwind," that is, a storm moving in a spiral comparatively small in extent but concentrated in force.

British Isles the cyclones generally move in the direction S.W. to N.E., the direction of the prevailing wind, at varying rates from 10 miles an hour to over 70. An approximate average is about 20 miles per hour. As the system moves, the whole of the spirally in-blowing winds move with it. It will be noticed that the winds do not blow square from isobar to isobar, but are deflected to the right, and this deflection gives the winds of the system a spiral movement towards the centre. The line *AB* (fig. 50), which is drawn at right angles to the direction of travel (path), is called the "trough"; it divides the system into a *front half* and a *back half*. The front half is the region of dense clouds and heavy rainfall; the back half is the region of light clearing-up showers, fleecy clouds,

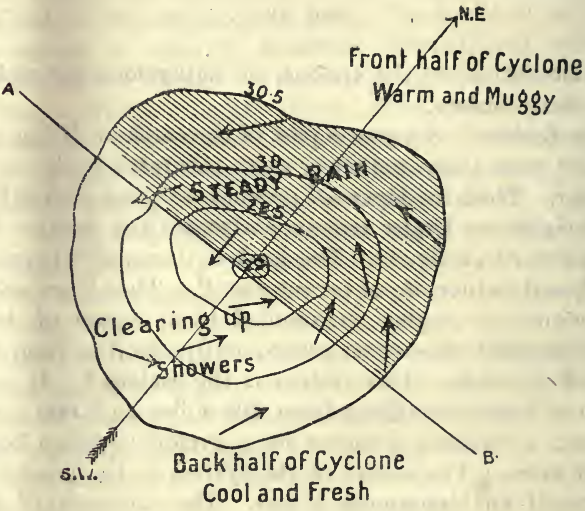

FIG. 50.

with bright sky between showers. The advent of a cyclone in the temperate zones is heralded by a darkening of the sky in the S.W., the darkening gradually spreading over the whole sky. As the darkening spreads, it drives in front of it light wisps of feathery clouds. The air is peculiarly close and muggy. When the front half has passed over, the air becomes very fresh and exhilarating. As the front half passes, the winds blow (in the northern hemisphere) more or less from the east; then as the storm-centre or the trough passes there is a period of calm; and then in the back half the winds commence to blow more or less from the west. In the southern hemisphere the wind directions would be reversed. The steepest gradients in a cyclone are, in the northern hemisphere, usually south of the centre. There is a tendency for the centres to follow a coast-line rather than to strike inland. The cyclone, then, may be defined as a system of winds blowing over a large area from a high-pressure belt on the outside towards a low-pressure region within. The

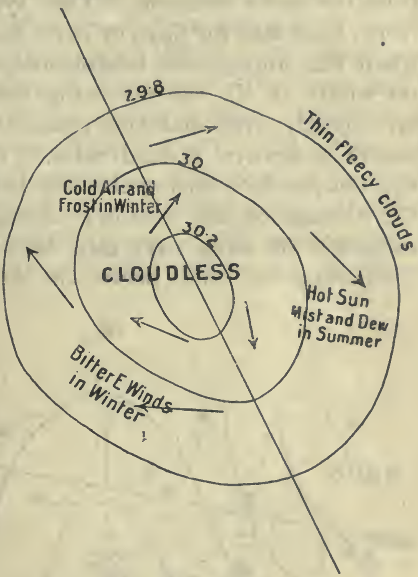

Fig. 51.

deflection of the winds due to the earth's rotation causes them to *blow spirally—counter-clockwise in the northern hemisphere—towards the centre.*

The Anticyclone.—In this system the high-pressure region is within and the low-pressure region outside (fig. 51). The winds therefore blow *spirally clockwise from the centre outwards.* This system, unlike the cyclone, may last for days or even weeks without moving; when the anticyclone is stationary, there are generally no winds at all, the air being quiescent. The isobars are slightly oval and the gradients very gentle. The centre is always a dead calm. Under an anticyclone the temperature during the day is high and often above the average of the season; at nights, owing to rapid radiation of dark rays due to absence of cloud, the temperature is often below the average. This fact ex-

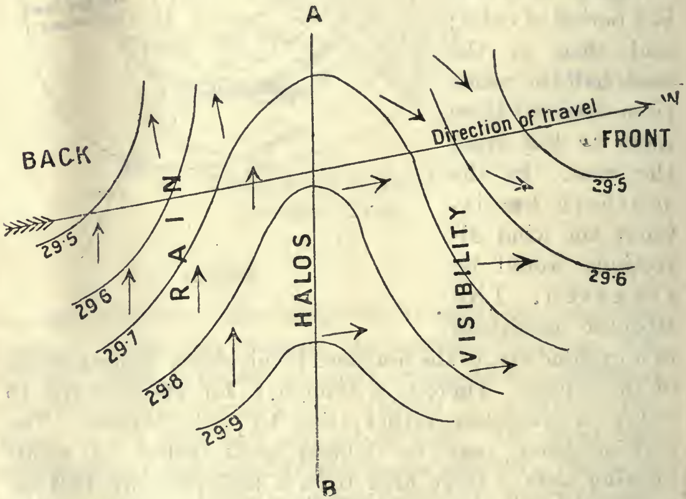

FIG. 52.

plains the diurnal extremes of heat and cold of Mid-Eurasia and of the central parts of the Americas. In the sunshine under an anticyclone it is often very hot and hazy.

The Wedge.—This consists of a wedge of high pressure between two cyclones. It has some very peculiar characteristics. In front the sky is cloudless and the air very transparent. This great transparency is known as **visibility.** Along the trough *AB* (fig. 52) there may be halos of the sun or of the moon. The back half is the region of a heavy downpour of rain. This system, like the cyclone, moves along the S.W. to N.E. line. It represents the isobaric character of those days that start fair in the morning and have rain during the afternoon.

The Secondary.—The full name of this phenomenon is secondary cyclone. It is a small cyclone (fig. 53) formed

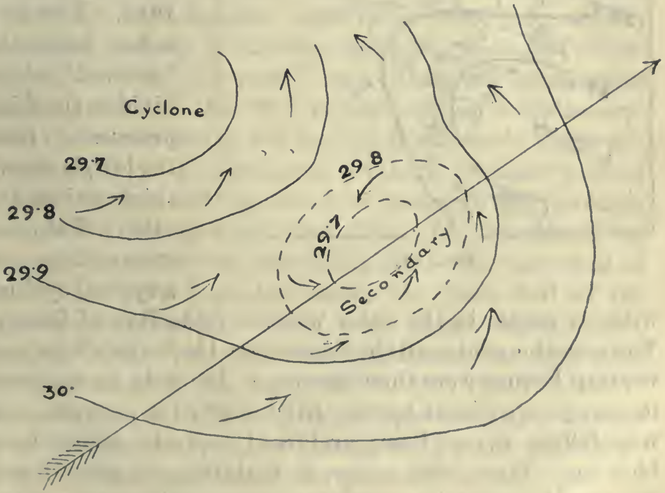

Fig. 53.

on the side of a larger one (the primary), and it travels in the same direction. The important feature of a secondary is the deflection of the isobars of the primary and the consequent alteration of the gradients. The sudden formation of a secondary within a primary cyclone completely upsets all forecast calculations. The steady downpours under a secondary are the heaviest rains we get.

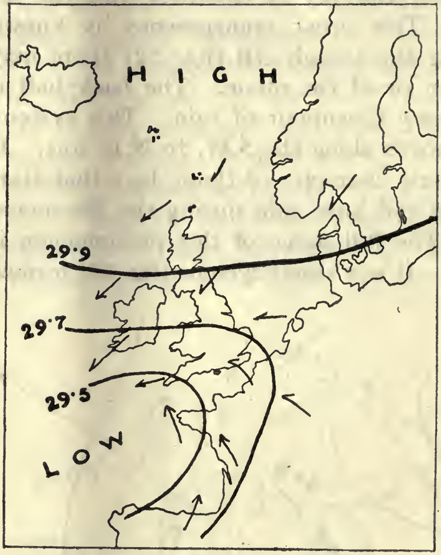

FIG. 54.

In fig. 54 are shown the pressure conditions that prevailed over the British Isles at 6 p.m. on October 6, 1913. The 29·9 isobar, being the "normal" which divides the high pressures from the low, is drawn thicker than the others. The pressure system was a typical cyclone with its centre in the outer waters of the Bay of Biscay. Towards this centre all the winds over the British Isles and western France were then blowing. As might be expected in a region covered by the front half of a cyclone, rain was falling everywhere, and cold easterly winds were blowing. There was no great variation in wind force, as the barometric gradients were uniformly gentle.

North of the "normal," towards Iceland, the barometer, though high, was steadily falling, an indication that the cyclone was moving in a more or less northerly direction. At 6 p.m. on October 7, the 29·7 isobar had moved from the position in fig. 54 to the position occupied on the 6th by the "normal"; which means that all along that line the barometer had dropped two-tenths of an inch in twenty-four hours. In that twenty-four hours the "normal" had moved up to Iceland, and the storm-centre had moved from the Bay of Biscay to Cornwall, where the barometer had fallen from 29·5 to 29·3. The winds continued easterly in front of the "trough" and rain continued falling everywhere. Most of the south-coast stations registered over 1 inch of rain on that day, and very few English stations registered less than ½ inch. On October 8 the storm-centre was in the Fen district, and the trough was then across the middle of Ireland and England with the barometer rapidly rising and westerly winds blowing in the back half of the cyclone. As the "normal" moved slightly southwards on the 8th, and the 29·7 isobar remained stationary, while the storm-centre was moving northwards, the gradients in northern England and southern Scotland became slightly steeper and the winds correspondingly stronger than during the two previous days. On October 9 the "trough" had moved sufficiently far north that most of the British Isles then lay under the back half of the cyclone, and suffered from only small, intermittent, clearing-up showers. The rainfall during the four days of the passing of the front half of this cyclone was in Retford 1¾ in., in Buxton 1¾ in., in Exmouth 1½ in., in Bath 1½ in., in Margate 1½ in., in Yarmouth 1¼ in., in Harrogate 1¼ in., in Blackpool only ¾ in., and in Rhyl only ½ in.

Variable Winds.—Special physical features of certain regions give rise to special variations of the permanent or planetary winds. As a rule, in the tropics, the permanent winds blow with such steady persistent regularity that local geographical conditions seldom disturb them. Outside the tropics, where great atmospheric changes of temperature occur over comparatively small areas, variable winds are common, the chief of which are :

The **Bora,** or **Tramontana,** is a sharp, dry, cold, north wind (Latin, *boreas*) which blows with fierce gusts from the Karst country at the head of the Adriatic along the coast of Dalmatia. It is caused by the proximity of the Alpine glaciers to the warm Mediterranean. The Bora is a wind of such extreme violence that it endangers the shipping in Trieste harbour, and in exposed spots in Trieste only stretched ropes can keep pedestrians from being blown down. The **Scirocco** (see p. 173) is the wind that blows up the Adriatic in the direction opposite to the Bora. On Bora days the maximum velocity of the wind occurs at 9 a.m. ; on Scirocco days the maximum velocity occurs at 6 p.m. A Bora storm sometimes lasts a week, and in January 1906 created a record by blowing at 80 miles per hour.

The **Bise** of Switzerland is a north or north-east wind which has the same cause as the Bora.

The **Chinook** is a warm westerly wind from the Pacific which reaches the Canadian Rockies as a saturated, moisture-laden wind. The moisture being precipitated on the western slopes of the Rockies, the wind blows down the eastern slopes as a dry wind. Because of the change from saturation to dryness which sets free the latent heat of the moisture; because of increasing compression as the air is drawn down from the heights into the valleys; and because of its southern origin, this wind has a temperature from 30° to 40° F. higher in the eastern valleys than at corresponding levels on the western slopes of the Rockies. Hence the winters of Alberta are much milder than those of more easterly districts, and stock can feed out of doors nearly all the winter.

The **east winds** in Great Britain blow in the late winter and early spring. They come from Russia across the Baltic, and are cold and dry but not at all harmful, though they are said to be " trying " to weaklings.

The **Etesian winds** are drawn from the north across the Mediterranean towards Egypt by the great heat of the Sahara in summer. They blow during the day, and, being north or north-westerly winds, are most useful to sailing craft going *up* the Nile. To these winds Egypt owes much of its fertility, since they carry the Mediterranean vapours across that country to the Abyssinian mountains, where they condense in torrential rains that help to flood the Nile. (They are sometimes called the " Egyptian monsoon.")

The **Föhn** wind of Switzerland is a south wind of similar origin to the Chinook, appearing on the *north* side of the Alps as a warm dry wind. The Föhn, because of its power as a disperser of snow, is called in the German Alpine Foreland the **Schneefresser** (snow-eater).

The **Gregale** of Malta is a cold, unhealthy, north-easterly wind; it is the Euroclydon which wrecked St. Paul.* Like the Etesian winds, the Gregale is drawn from the north by the superheated Sahara. It sometimes damages the shipping in Valetta harbour, and crops on the island have to be surrounded by stone walls for protection against it.

The **Harmattan** is a hot east wind peculiar to Senegambia and Guinea. Blowing from the interior, it is dry and parching, and often laden with clouds of reddish dust. It sometimes causes the skin to peel off; but it stops epidemics. It is in this respect like the south-east wind of Capetown, which, blowing from over thousands of miles of ocean, is locally known as the "Cape Doctor."

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* See Acts xxvii. 14.

The **Mistral** is a strong north-west wind peculiar to the south-east of France. It is produced from the end of autumn to the beginning of spring by the proximity of the warm Mediterranean to the comparatively cold Cevennes Mountains. The mistral is a violent, piercing wind, which, however, purifies a somewhat enervating climate. It is because of the mistral * (the "master" wind) that the old streets in Provençal towns are built very narrow and winding, so as to check its sweeping gusts. This wind, unseasonable and cold, sometimes prevails even in the Riviera.

The **Pampero** is a fierce north-west wind blowing in the summer from the pampas round Buenos Aires. It is much dreaded by sailors in the Plate Estuary.

The **Puna** winds blow for half the year over the barren Puna table-land of Peru and Bolivia which lies between the central and the maritime chains of the Andes. They are the last remains of the south-east trade-winds, and are therefore at first moisture-laden, but having been squeezed of their last particle of moisture by the lofty, eastern wall of the Andes, they arrive in Peru as dry, hot, and parching winds. According to Prescott, the ancient Peruvians preserved their dead by merely exposing the bodies to the action of this wind.

The **Simoom** † is peculiar to the hot deserts of Arabia and Africa. It is a suffocating wind which sometimes lasts no longer than ten minutes, and which, raising great whirlwinds of sand, is very dangerous to desert caravans.

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* Latin, *magister*, master.

† Arabic, *samúm*, from *samm*, "poisoning."

It is essentially of the same nature as a tornado or cyclone: there is a central tract of calm, which is surrounded by violent eddies of intensely heated air.

The **Scirocco** (or **Sirocco**) is a hot south wind which blows over Sicily, South Italy, and the Adriatic. It is a wind which is occasioned "when a low atmospheric pressure happens to arise on the borders of a hot desert region" (Geikie). In South Italy and Sicily it is hot, dry, and parching, a temperature of 110° F. having been recorded for it in Sicily. Farther north it becomes moist and cloudy. Both the dry and the moist scirocco give rise to giddiness or fainting by reason of their sultry and oppressive heat. In the Balkan peninsula it is called the **Samiel.**

The **Solano** is a hot south wind which prevails at certain seasons in the south of Spain. It is identical in character and origin with the scirocco. In northern Spain a cold moist wind, called the **Gallego,** blows from Galicia in the north-west over the plateau of Old Castile. Its origin is similar to that of the mistral.

Hurricanes are violent, stormy whirlwinds that occur in the tropical North Atlantic. In the tropical North Pacific they are called **Typhoons.** They never originate on the land, though they often pass over oceanic islands and low-lying coasts. But wherever they pass they deal destruction: on the sea, shipping is destroyed, as in the case of the German and American men-o'-war at Samoa in 1889 *; on the land, trees are uprooted, buildings thrown down, and often there is great loss of life.

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* On this occasion five vessels were stranded or lost; but the only British vessel, H.B.M.'s corvette *Calliope,* succeeded in working her way in the teeth of the storm out into the open sea. As the *Calliope* passed the American ship *Trenton,* the *Trenton's* crew, 450 strong (most of whom subsequently perished), gave three cheers for the British ship, and shouted, "Well done, *Calliope*!" The *Calliope* answered the cheers.

Tornadoes are violent whirlwinds that pass eastward along the Mississippi valley. They are sometimes a mile in width; they have the appearance of a funnel-shaped column of black cloud; they are accompanied by rain or hail; and often the air-pressure within the whirlwind is so low that there is actually a partial vacuum. These whirlwinds do almost incredible damage, as when the town of Lawrence in Massachusetts was nearly destroyed in July 1890. When a tornado develops over the sea it takes the form of a waterspout. As the column of black cloud approaches the surface of the sea, sea-water is drawn up to a slight extent by the low pressure within the whirl. The greater part of the water in a waterspout is, however, due to the condensation of water-vapour in the air, and not to the uplift of water from the sea.

Blizzards or **Northers** are violent, cold, north winds, accompanied by terrible snowstorms, that blow in winter over the western plains of the United States. As the mountains of North America trend north and south, there is nothing to check the onrush of these winds. They sometimes blow in the eastern regions, even east of the Alleghany plateau, but in this case they are somewhat milder in character than the true blizzard of the north-west. In 1888 a blizzard killed 200 persons in Dakota. In Devonshire in March 1891 occurred what is very rare in England—a snowstorm of this type, always spoken of as "the blizzard in the west." Trains were snowed up all over the county. Horses with drivers and riders perished within short distances of their homes, and there was great loss of life in various parts of the county. Thousands of trees were uprooted.* The snow in the lanes was 20 to 30 feet deep and was still lying in places at the end of May of the same year. No other parts of the country suffered.

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* The uprooting of the trees was due to the resistance offered to the fierce winds by the masses of snow accumulated among the branches. Mount Edgecumbe Park, near Plymouth, suffered very severely.

The **Brickfielder** of New South Wales and Victoria is a hot wind of the scirocco type blowing from the north. It is most severe in November, December, and January, the southern summer. Under its influence the temperature in Sydney has been known to rise to 110° F., and in Melbourne apples are said to have been roasted on the trees by it.

The **Southerly Buster** of Melbourne and the east coast of Australia is a strong, cool, cloudy, rain-bringing wind blowing from the south and south-east. It blows sometimes only for a few hours, but at other times lasts for a week or ten days. There is always a rapid fall of temperature with this wind.

Effect of Wind on Land-forms.—When wind blows over a field of grass, it blows nothing out of it, except it may be pollen; but when wind blows over a dusty road, it sweeps off some of the loose road-surface. These common facts illustrate the difference of wind action in a country that has a moist climate and in a country which has a dry one. In countries where the surface is more or less thickly covered with jungle, grass, or forest—which generally imply a moist climate—the wind has little effect upon land-forms. But in dry regions of scanty vegetation it is a most powerful agent of (*a*) **denudation** and (*b*) **transportation.** Just like a river, the wind raises the finer dust into the body of its current, but the heavier particles are borne along at the bottom of the wind-current and act as files and planes to the rocks over which they pass. This is noticeable in the Sahara, where there are uplands * with extensive surfaces of bare, polished rock, the dust or " filings " having been blown away and deposited on lower lands. Thus the wind is always adding to the amount of sand in the desert. In Kerguelen Island, in the Roaring Forties, wind-driven sand has actually cut west to east grooves in the exposed rock-surfaces. But the work of wind is even more marked in transportation. As the tropical sun's heat by day, alternately with the cooler nights, loosens fragments from the surface of a rock, the wind comes and removes them, and thus continually keeps the surface smooth and constantly exposed to the attacks of destructive action. It is this destructive energy, coupled with the mechanical rasping action of the wind itself, that tends in every desert region to increase the amount of sand. In the Sahara there was sand already, for in all probability it was an old sea-bed, but owing to the combined action of sun and wind there would have been sand anyhow. It is also the wind which piles up **dunes** or sandhills, and it is the wind which, by blowing up the sand on the windward side of the dune over to the leeward, actually causes the dune in some instances to alter both its shape and its position. It is in part this drifting sand which makes travelling in the desert so slow and so fatiguing. Dunes on the sea-coast, on the other hand, may prove of value against the inroads of the sea, as is the case in places along the eastern coast of Great Britain, the celebrated golf-links of St. Andrews, for instance, being protected against the sea by a range of high dunes. In the Bermudas the wind has covered the surface of the island with a fertile deposit of coral-sand, which is favourable to the growth of potatoes. Sometimes, however, the transporting power of wind has been directly destructive of human enterprise and endeavour. That has been so in Egypt, in Central Asia, and in Mesopotamia, where buried cities and the remnants of many successive civilisations are concealed beneath hundreds of feet of drifted dust and sand. In Central Asia is a desert stretching for thousands of miles. The larger part of it is called the Desert of Gobi; a smaller part, larger than the British Isles, lying between the Thian Shan Mountains and the Kwen Lun, is called the Takla Makan Desert. This is more dreary and desolate than any other region on the face of the earth. The red sand of this desert is blown by the wind into huge dunes two or three hundred feet high and more than a mile long, which, moved by the force of the wind, flow across the desert as waves of a mighty ocean of sand. Dr. Sven Hedin, the great Swedish traveller and explorer, in his journey across these deserts in 1899–1902 discovered under the sand of the Takla Makan not only buried forests but also the ruins of a great city, the tops of whose temples were showing above the shifting sand-hills. On the Kurische Nehrung at a point opposite the arrow in fig. 55 there used to be in the last years of the nineteenth century the remains of an ancient forest on the landward side of the Nehrung *—the belt or spit of land which separates the lagoon or *haff* from the Baltic. But the dunes, which travel annually about 20 feet eastward, flowed over the forest and the trees reappeared—dead, of course—on the seaward side of the Nehrung. At one time there were forests covering the whole length of the Nehrung, and they sheltered flourishing villages on the landward side. But during the Seven Years' War (1756–63) the trees were destroyed, the dunes began to travel, the fields were overwhelmed, and the inhabitants fled. On the line *AB* in the same figure (55), about one-third of the length of the spit from the southern end, there stood in 1809, according to Berendt's "Géologie des Kurischen Haffs,"

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* These stony uplands may be found in the desert south of Algiers and are known as *hammada*. They are most fatiguing to travel over.

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* Off Venice and in the Adriatic this lagoon-breakwater is known as a *lido*.

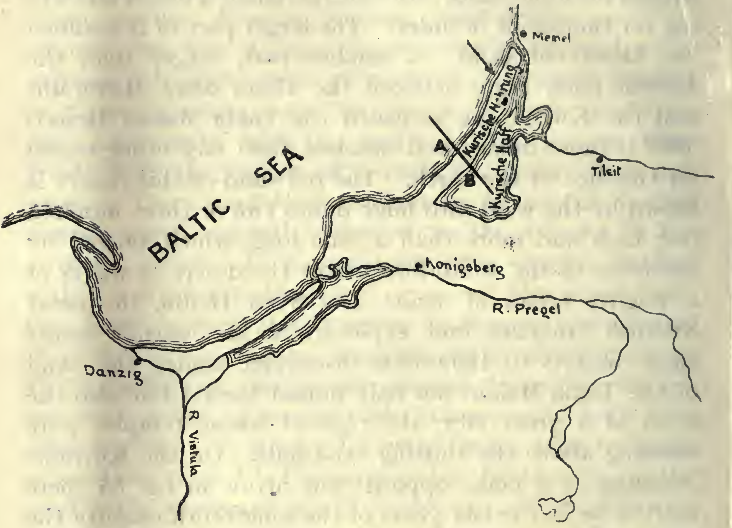

Fig. 55.

the church of the village of Kunzen. At that time a sand-dune had formed on the seaward or south-western side of the church (fig. 56). In 1839 the sand-dune, travelling along *AB* (fig. 56), had completely covered the church. In 1869 the dune had passed to the landward side of the spit, leaving exposed the crushed remains of the church. In the last years of the seventeenth century Downham, in Cambridgeshire, was partly destroyed by a sand-flood that covered more than 1,000 acres of land. On many sea-coasts, sand-drifts sometimes advance inland and cover up fertile districts with barren sand. Along the shores of the Bay of Biscay the sands used to advance inland at the rate of 60 or 70 feet a year. The Roman road from Bayonne to Bordeaux was obliterated in this way. The destructive work of "Æolian"* sand was in this district arrested by planting pine forests, the turpentine of which has become a source of considerable revenue. At San Francisco, shrubs have been planted on the coastal slope to prevent the sand of the shore from burying the Golden Gate Park; and on the New England coasts thousands of pounds have been spent in brush fences to keep the sands from doing damage. A most valuable result of wind-transportation is the formation of the

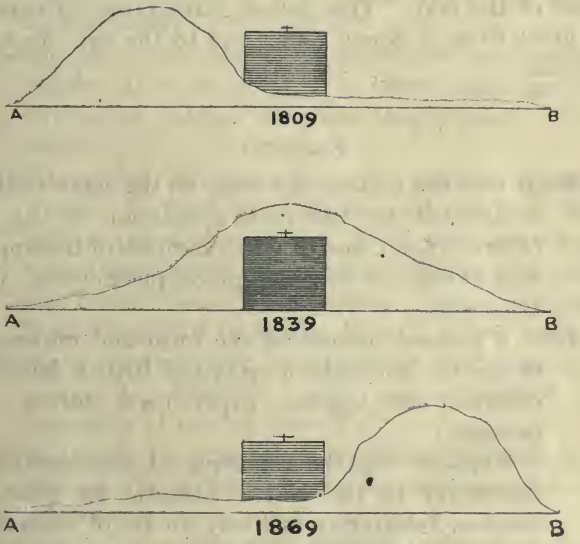

FIG. 56.

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* *I.e.* wind-blown, from Æolus, the god of the winds.

rich yellow earth known as **loess.*** This is a fine calcareous clay first discovered to the north of the Alps and among the Carpathians, but huge deposits of it occur in the north of China, where it is found to the depth of 1,000 feet. Millions of Chinese live on these loess lands; for the yellow earth is very fertile when well watered. This loess is a formation or accumulation of wind-borne dust of sufficient firmness to be excavated, and in parts of China (*e.g.* the province of Shan-si) dwellings have been cut out in tiers along the faces of the steep slopes of the clay. This yellow earth gives its name to the great river of North China and to the sea into which it flows.

EXERCISES

1. State how the motion of a body on the earth's surface is affected by the earth's rotation on its axis (*Ferrel's Law*), and discuss examples of the application of this law to geographical phenomena. (Oxf. Loc. Sen.)
2. Give a general account of the form and movements of the cyclones which cross the British Isles, and describe the weather experienced during their passage.

   Explain why the reporting of readings of the barometer in the North Atlantic by means of wireless telegraphy is likely to be of special use in forecasting British weather. (Oxf. and Camb. Sch. Cert.)
3. Describe the mean annual distribution of atmospheric pressure over the North Atlantic, and show how

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* The word is German, meaning "loose." Pronounce something like *less*.

this is related to the prevailing winds. (Oxf. and Camb. Sch. Cert.)

4. Some parts of Canada experience "föhn" or "chinook" winds. What are these winds? Where do they blow? How do they benefit the regions exposed to them? (Oxf. and Camb. Sch. Cert.)
5. Draw isobars showing (*a*) a cyclonic system in which the winds are strong, and (*b*) one of the same size in which the winds are light. Insert arrows showing the direction of the winds. (Oxf. and Camb. Lower Cert.)
6. Name the most important *permanent* and *periodic* winds. Give an account of their origin, and say over what part of the globe they prevail. (Civil Service.)
7. Write as full an account as you can of the trade winds. In what parts of the earth do they blow, and in what directions? How do they change with the seasons? Apply your answer to explain the course taken by a sailing ship on a voyage from Liverpool to South Africa. (Civil Service.)
8. Explain the character of the storms that come to us across the Atlantic. How can we foretell the approach of one of them?
9. Explain why in summer a sea breeze springs up at the seaside in the morning and dies away in the afternoon.
10. Which are the two most regular systems of winds on the globe? Where do we meet with irregular systems and with periodical winds? Say what you know about the last named.
11. Give the causes for the direction of the chief permanent and periodic winds. Enumerate the winds

and calms that a clipper would encounter going from London to Melbourne. (Civil Service.)

12. What are the monsoons and how do they differ from the trade winds? Account for their change in direction at the different seasons of the year. (Naval Cadets.)

13. Draw a map to show isobars and winds in a low-pressure system (cyclone), the centre of which (29 inch) is over the heart of England, while the pressure in Kerry is 29·7 inch, in Caithness 29·9 inch, and in Dover 29·5 inch. If it is moving due eastwards, explain the changes of wind during the next twenty-four hours at Dover. (Coll. of Preceptors.)

14. Give as complete an explanation as you can of the origin of "land and sea breezes" observed on the coasts of countries in low latitudes.

    Would this phenomenon be observed in an island in the trade-wind belt? Give reasons for your answer. (Oxf. Loc. Jun.)

15. Explain how our Meteorological Department forecasts weather. What areas have we of consistent high or low pressure in the North Atlantic? (Coll. of Preceptors.)

16. Draw a series of isobars showing the form of a typical cyclone and insert arrows showing the direction of the wind in different parts. (Oxf. Loc. Sen.)

17. Describe fully the measurements that would have to be taken and the calculations that would have to be made to construct an isobaric chart of a region at some particular date.

    What would be the use of such a chart? (Oxf. Loc. Sen.)

18. Explain what is meant by an isobar. Compare the

general arrangement of isobars over Asia in winter with their arrangement in summer. Account generally for the difference. (Oxf. and Camb. Lower Cert.)

19. What is a blizzard? Explain the causes of the phenomenon, and show why it is not commonly met with in Europe.
20. Distinguish between hurricanes, tornadoes, and typhoons. What are the characteristic features of the following winds, and where do they blow? —The simoom, the scirocco, the harmattan, the mistral, the monsoons.
21 " A zone of calms is an oscillating belt." Explain this.
22. Why are the south-west winds in Britain usually accompanied by rain, while east winds generally bring dry weather?
23. Describe the tracks followed by typical hurricanes and typhoons and compare them with the movements of the cyclones of the temperate zones. (Oxf. and Camb. High Cert.)
24. Name and describe the position of an island in the trade-wind belt. Describe the chief features of the weather experienced in it. Compare them with those of the weather in an island in the west-wind belt (*e.g.* Ireland). (Oxf. Loc. Jun.)
25. Describe the positions of the tropical belts of high atmospheric pressure. What are the consequences of their seasonal migrations? What parts of the earth's surface are chiefly affected by those migrations? (Oxf. Loc. Sen.)
26. " In the trade-wind belt dry regions are found towards the western sides of the land masses, while in higher latitudes they occur towards the east."

Explain the reasons for these facts and give examples in illustration of them. (Oxf. Loc. Jun.)

27. The trade winds help to cause drought in some regions and heavy rainfall in others. Explain this and give examples. (Oxf. Loc. Jun.)
28. What is meant by a monsoon wind? Describe in particular the conditions of temperature, pressure, and rainfall during the summer monsoon in the Indian area. (Manch. Univ. Matric.)
29. Point out the connection between areas of high and of low pressure and the direction of the wind. What influence has the rotation of the earth on the winds? In what direction do winds blow that are most altered in direction thereby? (Coll. of Preceptors.)
30. Explain how by means of a map on which isobars are drawn we can approximately estimate the force and direction of the wind. Why is it preferable to have isobars drawn for January and for July than for the whole year? (Coll. of Preceptors.)
31. Describe a distribution of barometric pressure which would give rise to easterly winds in the north of Scotland. Supposing this distribution to occur during the winter, what part of the British Isles would be likely to have the warmest weather? (Oxf. and Camb. Sch. Cert.)

CHAPTER XIV

The Moisture in the Atmosphere

Measurement of Humidity.—There is always water-vapour in the air, even over the Sahara Desert.* The amount present depends upon (1) the amount of water in the neighbourhood, (2) the temperature of the air. Most water-vapour exists in warm regions over the ocean; least in cold regions over the land. The actual amount in the air represents the **absolute humidity**; but as the same amount in air at different temperatures has different effects, absolute humidity is much less important than **relative humidity,** which is expressed by the proportion:

$$\text{relative humidity} = \frac{\text{amount of water-vapour present.}}{\text{amount possible at the temperature.}}$$

Thus, air at 50° F. is saturated with 4·06 grains per cubic foot. Therefore, if air at 50° F. contains 2 grains per cubic foot its relative humidity is $\frac{2}{4{\cdot}06} = \frac{200}{406} = \frac{100}{203}$ $= {\cdot}49$, or roughly ½, or 50 per cent. Again, if air at 50° F., saturated with 4·06 grains per cubic foot, were raised to a temperature of 68° F., it could then hold 7·47 grains per cubic foot, but with the 4·06 grains per cubic foot its absolute humidity would remain unchanged, while its relative humidity would change from 1 to $\frac{4\cdot06}{7\cdot47}$, *i.e.* from 1 to about $\frac{1}{2}$. That is, the same absolute humidity may be saturation for air at one temperature, but a small relative humidity at another temperature. The weight of water-vapour per cubic foot of air is measured by drawing the air through tubes containing pumice-stone saturated with sulphuric acid, and then finding the increase in weight of the pumice-stone for every cubic foot of air drawn through. The degree of humidity is measured by instruments called hygrometers. The one in most common use is Mason's **wet and dry bulb thermometer** (fig. 57). Round the bulb of the wet thermometer is a piece of fine muslin with an attached wick dipping into a small vessel of water, which by capillary action keeps the muslin constantly wet. The drier the air, the more rapidly will the water evaporate from the muslin; the more rapid the evaporation from the muslin, the more will the temperature of the wet bulb be lowered,* and consequently the greater will be the difference be-

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* The Sahara, like some parts of Central Asia which once contained large cities and are now desert, had once a much moister climate. Its *wadies* or dry river-valleys and the water-worn pebbles which they contain, are evidence of the one-time presence of large and constantly flowing rivers.

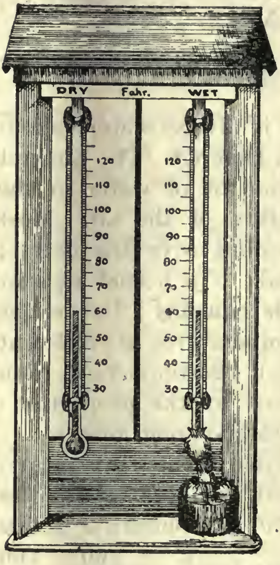

Fig. 57.

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* The mercury in the wet bulb contracts because it gives up its heat to cause the evaporation from the saturated muslin.

tween the temperatures of the two bulbs. In a saturated atmosphere no evaporation will take place, and the wet bulb will be no cooler than the dry bulb. So that the greater the difference between the reading of the wet bulb and that of the dry bulb, the drier is the air ; and the less the difference, the greater is the percentage of water-vapour in the air. When the dry bulb thermometer stands at 34° F. a difference of 2° would indicate a relative humidity of 79 per cent.,* a difference of 4° 63 per cent., a difference of 6° 50 per cent. When the dry bulb stands at 60°, a difference of 2° would mean 88 per cent. of relative humidity, a difference of 10° would mean 43 per cent. At 80° on the dry bulb, 2° of difference means a relative humidity of 90 per cent., and a difference of 10°, 50 per cent. (see Glaisher's tables.) †

In our climate the air is often saturated, *i.e.* has a relative humidity of 100 per cent., and very rarely indeed is the air so dry as to give a difference of 15° between the wet and dry bulbs. In parts of Australia, India, and other hot, dry regions, the air is often so dry as to contain only 10 per cent. or less of water-vapour, and the difference of readings may be as great as 50° or 60°. Now hot, dry air is much easier to work in than hot, moist air, and, indeed, is much healthier. So that when in, say, New South Wales the dry bulb thermometer stands at 110° F. (as it often does in their summer), no distress is suffered if the wet bulb is low enough to indicate that the air is dry (say 70° F.). Discomfort arises when both wet and dry bulb are very high. Therefore, when in the newspapers we read that a cricket match was played in South

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* 100 per cent. would mean that the air was saturated.

† These tables were prepared by Mr. James Glaisher, one of the founders of the Royal Meteorological Society. Most standard text-books on Meteorology contain an abstract of the tables.

Australia with the dry bulb thermometer at 110° F., we cannot conclude that the thermal conditions were at all inconvenient unless we know at what height the wet bulb stood. To an invalid it is often much more important to know the relative humidity of the atmosphere than to know its temperature. The relative humidity of the warm air in a greenhouse is an important factor in successful floriculture. The use of the wet and dry bulb thermometer is compulsory in the cotton-spinning factories of Lancashire, where moisture in the air is essential for successful spinning and weaving.

Condensed Water-vapour.—Until condensation takes place the water-vapour is invisible, and condensation does not take place even when the air is saturated with water-vapour unless there is a lowering of temperature. The necessary lowering of temperature may take place in many ways, *e.g.* by radiation, by contact with a cold surface, or by rising into higher regions. When condensation takes place the vapour changes to minute particles of water. Air which is saturated with water-vapour ceases to be saturated if the temperature of the air be raised, since at the higher temperature the air can hold more vapour. Conversely, air which is not saturated at any given temperature becomes saturated if the temperature be lowered to a certain definite point. This point is called the limit of saturation, or **dew-point**, because, if cooling proceeds to the least possible extent below this point, condensation commences, and dew is produced. Dew-point, then, is *that temperature of the air at which dew starts being formed*, or at which condensation commences. The various forms that condensed water-vapour may assume are :

1. Dew or hoar-frost.
2. Fog or mist.

3. Cloud
4. Rain or hail or snow.

What form is assumed depends upon how and where the condensation takes place.

Dew and Hoar-frost.—Dew is a deposition of moisture from the air resulting from the condensation of that moisture on substances that have become cooled by the radiation of their heat. There are many familiar instances of the formation of dew, *e.g.* breathing warm moist breath on a cold pane of glass, the tumbler of cold water brought into a warm room, the blurring of spectacles when the wearer comes into a warm room out of a frosty air. For the formation of dew there must be water-vapour in the air, and the solid body with which the air is in contact must be cooled to dew-point. Some of the water-vapour for forming dew *comes up from the ground* as well as from the air. Place a sheet of glass (XY, fig. 58) over the ground on four pegs or corks in the evening, before dew forms. After the formation of dew examine the glass; there is dew *on* the glass, but it is mostly *under* the glass. Again, when dew forms on stones by the wayside it is the underside of the stones that is wettest. Therefore, *some at least* of the water-vapour required for the formation of dew comes up from the ground. The temperature of the earth's surface is usually on a clear still night lowered by radiation, and the water-vapour in contact with the cooled surface, or the water-vapour in the air among the constituent particles of the soil, becomes chilled until it

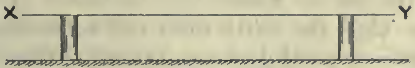

FIG. 58.

forms on the ground into droplets of dew. In the tropics, where the air is very warm and moist, dew forms at night in very large quantities. In our own country, after a warm summer's day, if the evening is cool, grass becomes quite wet with dew before it is dark.* Dew forms most readily on those bodies that radiate their heat most quickly. This is why grass, wool, leaves, etc., which are bad conductors but good radiators, are covered with dew more quickly than the soil below them. The air in contact with the ground may be prevented from falling in temperature to dew-point if it is constantly renewed by winds blowing over the ground; and if the wind is warm and dry it will cause to evaporate and will pick up any dew formed before the wind began to blow. If the night be cloudy, the clouds check the radiation of heat from the earth, so that the earth does not become sufficiently chilled.† There is most dew formation in autumn, because the surface of the earth is then warm to some depth and the air on the surface cooler. The heat down in the ground causes evaporation, and this evaporated vapour condenses in the cool air at the surface of the ground. In spring as well as in autumn the differences in temperature between day and night are greater than at other seasons, and the dew-point in both these seasons is therefore more quickly and more certainly reached. It is important to remember the distinction between dew and other forms of condensed water-vapour. Dew is formed upon a solid body whose temperature is below dew-point; if condensation takes place in the air because its temperature falls, fog, mist, or cloud is formed. Hoar-frost is the same as dew, but it is formed when, the dew-point being below 32° F., the water-vapour condenses as small particles of ice.

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* In South Africa, Kafir stock-thieves are sometimes traced by the *dew-spoor*—*i.e.* by the track the oxen or sheep leave as they are driven through dew-laden grass or herbage.

† The reverse is, of course, the case on a clear, starry night.

Fog and Mist.—In the case of mist and fog, condensation takes place in the air, not on solid surfaces. It has been found that water-vapour condenses much more readily when there is much dust in the air. Indeed, there can be little doubt but that condensation is helped by the floating impurities of the atmosphere. In a town where there is much solid impurity in the air, the fogs are always yellower and dirtier than those of country districts.* So that it is possible that the dust particles act as cold centres or nuclei round which the water-vapour more readily condenses. In fact, in a saturated atmosphere at dew-point, fog sometimes does not form for the reason that the air is too free from dust. In such a case, if you walk through an atmosphere of that kind, the water-vapour will condense on your clothes as dew, and yet there will be no sign of fog or mist. The characteristic feature of fog and mist is that the particles of condensed vapour, being very light, remain suspended in the air. The only difference between fog and mist is that in the latter the water droplets are larger than in the former, *i.e.* a mist is wetter than a fog, or, as some say, mist is a stage transitional between fog and rain. There are three theories to account for the formation of fog. One is that the intermixture of two masses of air at different temperatures produces fog. For when saturated:

1 cubic foot of air at 32° F. contains 2·14 grains water-vapour.
1 cubic foot of air at 68° F. contains 7·47 grains water-vapour.

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* London fogs used to be a terror to all who had to endure them, but of late years, owing to the enforced consumption of factory smoke and other causes, they have not been so formidable.

∴ 2 cubic feet of air at 50° F. contain 9·61 grains water-vapour.

∴ 1 cubic foot of air at 50° F. contains 4·805 grains water-vapour.

But 1 cubic foot can only contain 4·06 grains,

∴ (4·805 − 4·06) = ·745 grains which must condense out.

Another theory is that fogs are produced by cool air moving into warm moist regions. In the warm regions the ground gives off water-vapour, and the cool air reaching this condenses it, just as cool air will condense the steam over a warm bath. In November and December, while the ground is still warm from the summer heating, the cool east winds reach London and produce the famous London fogs. But in January and February, when the ground is cool, the fogs do not appear. These two theories also account for the fogs on the banks of Newfoundland. Here the warm Gulf Stream is side by side with the cold Labrador current (see p. 282), and the fogs are produced both when the cold air over the one stream mingles along the line of contact with the warm air over the other, and when the cold air of the northern current blows over the warm stream. Reikjavik, the name of the capital of Iceland, means "smoky" or "foggy" bay, and the fogs are the result of the meeting of the cold air which hangs over the Greenland current and the warm air which accompanies the Gulf Stream drift current. The third theory, that fogs are caused by warm air blowing into a cool region, seems unsound. This cannot form fog, for the same reason that you cannot have steam over a cold bath. The warm air may bring water-vapour, but this would condense on solid objects and form dew.

Clouds.—A cloud is a mist high up in the atmosphere; mist or fog is a cloud near the earth. The thinnest and lightest clouds are highest up, the darkest and heaviest clouds are only a short distance up. Clouds are not always composed of water particles; for the highest kind of clouds is composed of tiny ice spicules or needles. The reasons for believing that the highest clouds are thus composed of ice particles are, first, that at such a height (6 to 10 miles) water could not exist in the liquid state, and secondly, that light passes through them and throws no shadows. A study of the higher clouds teaches us a good deal as to the movements of the upper atmosphere, while the clouds lower down act as "heat curtains"; they neutralise the excessive heat of the sun by day, and at night they condense the heat of the earth by checking radiation.

The four chief types of cloud are the *stratus*, the *cumulus*, the *cirrus*, and the *nimbus*. When once the four chief types are grasped, names can be easily invented for intermediate types—*e.g.* cirro-cumulus, cumulo-stratus, etc. The *stratus* or streaky cloud is formed by one air-current passing over another at a different temperature, as in fig. 59. Between the two currents of air a flat stratus cloud, *XY*, would be formed. Sometimes the condensing layer is not flat but crumpled; then bars of stratus cloud are formed across the sky at those points of the crumpling nearest the cold current at *XXX* (fig. 60). This is called "mackerel sky." The mackerel sky is also caused by rapid and choppy dynamical cooling

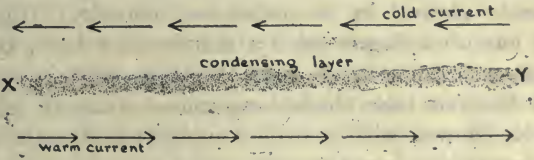

FIG. 59.

(*i.e.* cooling by rising and expansion) in the upper atmosphere. The *cumulus* or woolpack cloud is a rounded billowy cloud somewhat hemispherical in shape, and having the appearance of masses of steam and smoke from a steam-engine. It is produced by an ascending current of warm air the vapour of which is cooled quickly by expansion at an average height of about one mile (lower in mountainous country) (fig. 61). These cumulus clouds have a definite flat base, because it is at a definite level that the dew-point is reached. Above the flat base the billowy masses take all kinds of fantastic shapes, with conspicuous light-and-shade effect, made especially beautiful when lighted up by the rays of the setting sun. The *cirrus* or mare's tail is a light, wispy, feathery cloud formed at very great heights (up to ten miles or more) at a temperature below freezing-point. It consists of ice particles, is very transparent, and contains no light and shade as do the masses of cumulus cloud. In a cyclonic system of winds the air is always blowing towards the inside, and it would seem that the low-pressure area within ought to get filled up. But the fact that cirrus clouds are to be seen streaming out above and in front of the bank of dull cloud whose approach from the S.W. heralds the coming of the cyclone, shows that the in-blowing air is escaping in the upper regions. Hence, if, on a summer morning, at or soon

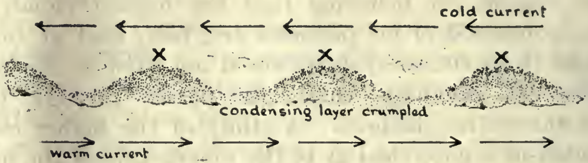

FIG. 60.

after sunrise, cirrus clouds are seen forming on the top of a pack of cumulus cloud, rain will fall from that cloud within an hour. If, however, stratus clouds form on the top of cumulus, no rain will fall. The *nimbus* or dark rain-cloud is the one from which rain is falling. It has no special form, but its colour is unmistakable. It is of a dark grey, almost dark slaty colour, and has nearly always fringed edges. It is the cloud into which other clouds resolve themselves when rain is about to fall.

Rain.—The water particles of a cloud are always falling by the action of gravity. The movement of the particles is exactly the movement of chalk-dust as it slowly falls downwards in a tumbler of water. Thus the particles from the upper parts of the cloud are always sifting down among the lower particles. On reaching the lowest layer of the cloud these falling droplets evaporate and pass back to the upper part of the cloud as vapour, there to be condensed and fall again as before. This process takes for granted a definite level in the atmosphere at which the cloud particles reach a temperature above dew-point. This, however, does not always exist. When it does

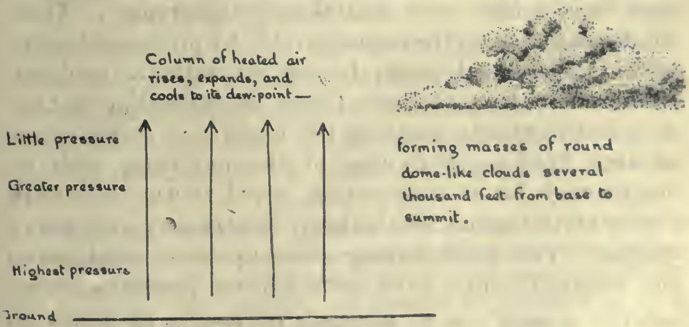

Fig. 61.

not, the particles on nearing the base of the cloud begin to unite and form *drops* of water. The mass of the new drop is, of course, equal to the sum of the droplets that form it; but the surface of the new drop is not equal to the sum of the surfaces of the droplets that form it.* Hence the drop is heavier in proportion to its size than its composing particles were, and the new drops—that is, the raindrops—fall much more rapidly through the cloud. Again, their proportionally small surface (with respect to their increased weight) affords less opportunity for re-evaporation, and consequently they now, as raindrops, first tend simply to remain at the base of the cloud. Reinforcements of similarly increased drops finally increase the mass of the drops at the base until it begins to sink, and if the air upon which the cloud rests is saturated, the base gives way and the drops reach the earth as rain. If the air should be very dry, re-evaporation may take place before the drops reach the earth. Raindrops often increase in size as they fall, either by aggregation or by condensing on their cool surfaces the water-vapour of the air through which they fall. Rain is also caused to fall when warm moisture-laden winds from over the sea blow over coastal mountain ranges. These winds are forced up the mountain side by pressure of winds behind, and chilled, partly by contact with the cool surface of the mountain itself, partly by expanding as they rise, and partly by reaching the upper and cooler layers of air. This rapid cooling of the moisture, with no opportunity for re-evaporation, gives to the windward slopes of the mountains a fairly continuous and heavy rainfall. The winds having given up their moisture on the windward side, have none left for precipitation on the leeward side. The dryness on the leeward slopes of coastal ranges is called the **rain-shadow.** In Great Britain the influence of cyclones tends to a more equal and general distribution of rain, and even the leeward slopes of mountains receive plentiful moisture. But, all the same, the prevailing westerly or south-westerly winds which bring moisture from the Atlantic set up a very marked rain-shadow in districts which lie to the immediate eastward of mountainous regions. The rain-shadow is very pronounced behind the high barrier of the Central Grampians to the *lee* of Cairngorm, Ben Macdhui, and Lochnagar. It is for this reason that in the neighbourhood of these mountains it is possible to enjoy a cool summer temperature without the torrential rain that characterises mountain districts almost everywhere else in Great Britain. This accounts for the popularity as summer resorts of Ballater, Braemar, and other places in the valleys of the Dee and the Don. Winds laden with moisture may sweep over such regions as the Desert of Sahara, the Arabian Desert, or the Thar Desert, without having their vapour condensed. In fact, the hot sandy soil produces the opposite effect, and renders the air capable of taking up more moisture. Many of the arid deserts of the world are the result of rain-bearing winds being forced to deposit their moisture through having to cross some range or ranges of mountains before reaching the desert area. Some notable examples of this fact are the Kalahari Desert * in South Africa, and the Atacama

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* This is easily seen by comparing the formula for finding the area of the surface of a sphere with that for finding its volume.

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* The term "desert" as applied to the Kalahari is somewhat of a misnomer, for much of its surface is a fairly good cattle-raising country. A desert, indeed, is not always or everywhere to be thought of as a dreary waste of sand. In parts of the Sahara even, away from the oases, the soil can produce a scanty growth of grass, enough to support the horses and camels of the wandering Bedouin.

Desert in South America, both of which are situated near the sea-coast. In South Africa the Kalahari Desert is due to the south-east winds being robbed of their moisture while crossing the Drakensberg Mountains in the east; in South America the Atacama Desert is caused through the south-east trade winds precipitating their moisture on the eastern slopes of the Andes. But the south-west anti-trade blowing to the Rockies brings rain all the year round to the coastal regions of western Canada, and also to the western United States coasts, when it blows farther south in the winter. Southern Chile is exposed all the year round to the Brave West Winds from the Pacific, and so enjoys a temperate moist climate throughout the year. The prevailing wind of Europe is the south-west anti-trade, and this explains why the southern and western slopes of the mountain ranges are in Europe more rainy than districts lying to the north and east of them. Thus Bergen has an annual rainfall of 90 in., Stockholm only 17; Genoa has 52 in., Berlin only 23; Trieste has 43 in., Budapest only 24; Smyrna has 26 in., Astrakhan only 6; Lisbon has 30 in., Madrid only 16; Galway has 52 in., Dublin only 30; Skye has 103 in., Aberdeen only 30; Penzance has 42 in., London only 25; and so on. In the British Isles, Ireland is the first to receive the rain-bearing winds from the Atlantic, and many places on the west coast have 80 in. of rain in the year. Scarcely any part receives less than 30 in., and as a consequence the island is so covered with rich grass that it well deserves its name of Emerald Isle. In England the western and south-western coasts have abundant rains. Devonshire and Cornwall have 50 in., some parts of Wales 70 in., and the Lake District 130 in. of rain per year. Hence we find that western England is the part most largely devoted to pasturage and dairy work, and Devonshire cream, Gloucester cheese, and Cheshire cheese may be called the produce of the south-west wind. Eastern England, being drier (London averages only 25 in. a year), is more suited to cultivated crops, such as corn in the east and hops and fruit in the south-east. This does not mean that there is no pasture land in the east of England, nor that there are no cultivated crops in the west. Cambridgeshire butter is considered by some people to be as good as that of Devonshire, and in the drought of 1911, when East Yorkshire, Lincolnshire, and the Fens were too dry to produce a potato crop, Lancashire and Cheshire supplied the deficiency.

Snow.—If water-vapour condenses in the air at a temperature below freezing-point, it assumes the form of interlocked crystals of ice known as **snowflakes.** Each crystal is built up hexagonally, and if one is examined under the microscope, it is found to be a design of great beauty. More than 1,000 different kinds of crystal have been observed, but each shower generally consists of one kind only. Snow is to rain what hoar-frost is to dew. It is not frozen rain. Sometimes, in winter, a rainstorm is due to what started as a snowstorm, but the crystals melted in their course downwards. This change is well shown when, from the same storm, snow falls upon the tops of mountains and rain in the valleys. A damp, slushy snowstorm (**sleet**) is such a change partially developed. In the British Isles the snowfall is rarely great enough to cause serious inconvenience except when accompanied by wind and consequent drifting, and then in railway cuttings and other sheltered places it accumulates to an extent limited only by the depth of the sheltered place. In the New England States of America the average annual snowfall is from 5 to 7 feet.* In the

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* A foot of freshly-fallen snow is equal to 1 inch of rain.

Arctic regions and in Northern Siberia, though the fall is not much greater than this, the snow lies a much longer time unmelted. In the torrid zone, except on the tops of high mountains, snow is almost impossible, though not unknown. The sudden melting of snow often causes dangerous floods, such as occur when the föhn wind blows over the Alps; but the gradual melting of hill-top snows is a common source of water-supply for rivers. The Nile floods are partly due to the melting of Abyssinian snows. The loose texture of freshly fallen snow makes it such an admirable non-conductor of heat, that in the valleys and plains of the temperate and sub-arctic regions snow often preserves the ground from the chilling action of spells of severe cold, and so enables to survive much plant life that would otherwise die.

Hail.—Sometimes the condensed water-vapour reaches the earth as balls of ice known as **hailstones.** Because hailstones frequently precede thunderstorms and violent windstorms like the tornadoes of the Mississippi valley, they are believed to be in some way connected with the electrical state of the atmosphere. Contrary to popular opinion, true hail, as distinct from snow pellets which often fall in winter, is almost entirely a summer occurrence, though hailstorms do occur sometimes in the late spring. The conditions favourable to the formation of hail of the ordinary small type seem to be great heat, a still atmosphere, the production of strong local convection currents, and the passage overhead of a cold, upper air-drift. The hailstones are probably formed by frozen particles of moisture first descending into a warmer cloud and receiving a fresh coating of water-vapour. Thence they are carried upwards by the ascending convection currents into the cold upper drift, where a fresh coating of water-vapour is frozen upon the original particles. This process is repeated, and the hailstone grows until it falls to the ground. At times several hailstones are frozen together until rugged masses of ice are formed, occasionally reaching huge dimensions. Very large, single hailstones are also formed when the hailstorm is attendant upon violent whirlwinds, since their powerful ascending currents are able to carry aloft into the freezing region stones of extraordinary size. The stratified structure of hailstones is easily seen when the mass has been cut through, the successive coatings of ice or alternate coatings of ice and snow indicating the method of formation. In the summer of 1889 hailstones were unusually destructive on the continent of Europe. In Moravia, for example, hailstones fell which weighed 3 lb., and many people as they worked in the fields were killed by them. In South Africa hailstones have been known to pierce the corrugated iron sheeting of huts and barns. The great hailstorm of 1788, which travelled across France from the Pyrenees towards Holland, is the most disastrous on record. Over 1,000 towns and villages were devastated, and damage was done to the extent of a million pounds sterling.

EXERCISES

1. Distinguish between a *saturated* and an *unsaturated* vapour, and define the term *relative humidity*.

   How is the relative humidity affected when moist air moves over land—

   (*a*) from a higher to a lower latitude ?

   (*b*) from a lower to a higher altitude ?

   Give geographical instances of important climatic effects produced by currents of moist air moving under the conditions cited above. (Oxf. Jun. Loc.)

2. "The capacity of the air for vapour is regulated by its temperature." Explain this. How can the height of the atmosphere be approximately determined? What are the main causes of the variations of atmospheric pressure at a given place?

3. The basins of the Nile and Mississippi are each about 1·3 million square miles, or about 40,000,000 million square feet in area. The average daily rainfall is about 0·01 foot in the Nile basin, and 0·008 foot in the Mississippi basin. The average daily discharge of the Nile is about 10,000 million cubic feet, and of the Mississippi 50,000 million cubic feet.

   Find what fraction of the rain which falls in each basin is discharged to the sea, and account as fully as you can for the differences between the two results. (Civil Service.)

4. Describe the mode of formation of hoar-frost, and the conditions under which it takes place.

5. What becomes of the water of puddles when they dry up, and what conditions of the air are most favourable to the process?

6. Why is water sometimes called the "universal solvent"?

7. What are the general conditions that lead to the formation of rain? What are the chief ways in which the upward movement of the air is brought about?

8. What is the snow-line? How is the indefinite accumulation of snow above the snow-line checked?

9. Explain the origin of sea-fogs and of black fogs.

10. Describe a wet and dry bulb thermometer, and state what inference can be drawn from its readings.

11. How is dew formed? State the conditions of the atmosphere which interfere with the formation of dew, and explain why they interfere.
12. Describe the formation of fog. Explain the prevalence of fogs—(*a*) off the coast of Nova Scotia, (*b*) in London. (Camb. Sen. Loc.)
13. What is meant by "dew-point," and how is it determined? (Oxf. Jun. Loc.)
14. State the part played by aqueous vapour in the atmosphere, with regard to (*a*) heat received from the sun, (*b*) heat radiated from the earth. (Oxf. Sen. Loc.)
15. On what does the feeling of *dryness* of the atmosphere depend? Describe, with a sketch, any instrument by means of which the dryness of the air can be measured numerically.

    Is the *dew-point* the same as the temperature of the wet bulb thermometer? (Give reasons for your answer.) (Oxf. Sen. Loc.)
16. Explain the deposition of dew, and state the best conditions for its formation. (Oxf. Jun. Loc.)
17. What is meant by the hygrometric state of the atmosphere? Describe any form of hygrometer and the method of using it. (Oxf. Sen. Loc.)
18. Explain why a wet cloth hung up in the open air will dry much more rapidly on some days than on others. What are the conditions that favour rapid drying?

    Give an example of a region where the atmosphere is always very moist, and account for the condition. (Oxf. Jun. Loc.)

CHAPTER XV

Climate

Climate and Weather.—Climate means the average state of the weather. Weather means the present conditions of the atmosphere with respect to temperature, pressure, winds, and rain. Climate denotes what we may expect to have; weather denotes what we are getting. The climate of a region can be ascertained only by taking the average of a great number of observations each year for many years; or, putting it another way, climate is the sum of different sorts of weather conditions. When weather has been thus summarised or averaged, it is usually easy to discover the causes that produce these average conditions. The local changes and differences over small areas, when taken together, make up the climate of a larger region. The chief **causes** determining or affecting the climate of any region are, (1) the latitude or distance from the equator, (2) the altitude or height above sea-level, (3) the distance from oceanic waters, (4) the prevailing winds, with the currents dependent upon them.

Latitude.—The earth is considered as being divided into the following climatic belts or zones:

1. The **torrid** zone, lying within the tropics from 23½° N. to 23½° S.

2 and 3. Two **temperate** zones, the north and south, lying between 23½° N. or S. and 66½° N. or S.

4 and 5. Two belts or caps called the north and the south **frigid** zones, lying round the poles at a distance of 23½° from each pole.

As the sun is the primary factor in the climate of a region, and between the tropics the sun's rays are always vertical at some point or another, the torrid or tropical zone is the hottest. Where the rays of the sun fall most obliquely upon the earth's surface—in the frigid or polar zones—the amount of heat coming from the sun is least. (See law of illumination, p. 76.) The torrid zone is characterised by high temperature, the frigid zones by low temperature, throughout the year. The temperate zones receive a fair amount of the heat of the sun, and are characterised by a marked difference in the average temperature of the opposite seasons of summer and winter. Therefore, speaking generally, the effect of latitude on climate is a progressive diminution of temperature the farther you get away from the equator. If the earth's surface were all land at a uniform level, or all water, and there were no winds, the locus of a difference of climate would always be a parallel of latitude.

The Polar Climate.—At the north pole is the Arctic Ocean almost surrounded by land; at the south pole is the Antarctic continent surrounded by ocean. Within the Arctic circle all the land fringing the ocean and all the islands in the ocean are frozen deserts in winter; in summer the surface thaws to the depth of a few inches and shallow-rooted, stunted plants appear. It is here that the tundra region occurs. In all tundra regions the characteristic vegetation is mosses of all kinds which lie dormant under the snow during the eight months of winter, and produce their spores in the short, hot summer. The barren lands of the American Arctic shores are much more inhospitable than the corresponding tundras of the Eurasian Arctic shores. During the brief, intense summer of northern Siberia berry-bearing bushes that grow in the moss-covered ground ripen their berries, brilliant flowers, such as gentians, poppies, and anemones, flourish for the moment, and mosquitoes abound. The Eskimos of the New World are able to live under conditions much more severe than the tundra people of the Old World. They live entirely by hunting and fishing, but being almost exclusively a coastal people, fishing is the main occupation. The Lapps and Samoyedes with their herds of reindeer are better off than the Eskimos, though in Labrador (which, albeit south of the Arctic circle, is a tundra region) Dr. Grenfell is teaching the Eskimos to make use of the reindeer, both as a milk and flesh provider and as a substitute for the sledge-dog. At the other pole, on the Antarctic continent, there are no signs of vegetation and no human inhabitants. Within the frigid zones the climate is throughout the year intensely cold and dry.

The Tropical Climate.—Within the tropics throughout the year the climate is extremely hot and, for the most part, moist. The torrid zone is not only the hottest part of the earth because of the vertical sun, but it is also, from about 10° N. to 10° S., the wettest because of its almost daily heavy rainfall (see p. 227). In this belt of the torrid zone, then, there exist the very conditions that favour the easy and rapid growth of vegetation, so that forests of gigantic trees of maximum hardness with a thick undergrowth of shrubs and creepers form the characteristic feature of the equatorial belt of tropical lands. These dense, hot, tropical forests occur in Brazil, Venezuela, Honduras, Congo State and Central Africa, Madagascar, Malaysia, and the East Indies. In the West Indies and Ceylon the original forest is being cleared for the purposes of cultivation. In these hot, moist regions of the tropical forests and beyond to the limits of the torrid zone, both north and south, the white man has to contend with climatic conditions so terrible in their effect that certain districts, such as Sierra Leone in West Africa and the low marshy country of Ceylon, are named the "white man's grave," because they are hot-beds of malaria. The danger of sunstroke and heat-apoplexy is also very great, especially if in these tropical climates men wear heavy or tight clothing about the body. Malaria and yellow fever, though not confined to the tropics, are especially virulent, the latter in West Africa, Mexico, and the West Indies, the former in East Africa and the East Indies. The source of infection in both these fevers is a mosquito * which carries the fever microbe from man to man. By taking proper precautions, however, the white man can and does establish himself healthily near the sea on the edges of the tropical forests, and carries on the work of superintending the methodical cultivation of tropical plants for commercial purposes.

Within the torrid zone the forest lands give place first to grass lands with scattered trees, called **savannah** lands. These districts, such as parts of the Sudan, Rhodesia in Africa, and the **llanos** of S. America, have all the appearance of an English park. Here the climate, though still very hot, is healthier than in the moister heat of the forest belt. Beyond the savannah lands are hot **deserts,** such as the Sahara in North Africa and the Kalahari in South Africa.

The Temperate Climate.—In Africa the temperate zones commence beyond the deserts; in Asia and America the desert regions extend beyond the torrid zone into the temperate zone. In the temperate zone the climate is marked by four regularly recurring seasons with a fairly abundant and regularly distributed rainfall. The summer temperature is well suited to the growth of grass and deciduous trees; the winter temperature is never such as to kill plant life, which merely lies dormant, being well protected by nature till the following spring. Those parts of the temperate zone, lying on the borders of the deserts, that have dry summers and fairly wet, cool winters are called Mediterranean regions, because that is the general character of the climate of countries that border the Mediterranean Sea. The Barbary States of Africa, southern Europe, California, Victoria in Australia, and the Cape of Good Hope are examples of this type of climate. In Mediterranean regions the typical trees and plants are the mulberry, orange, lemon, fig, olive, and lime-fruit, plants with leathery or tough leaves like the laurel or esparto grass, and plants which have long roots to find moisture deep down during the hot summer. The parts of the temperate zone nearer the tundra regions are characterised by cone-bearing trees such as pines and firs. In Alaska, because of the warming effect of the Kuro Siwo current, forests of these trees are found considerably north of the Arctic circle; in Labrador, because of the chilling effect of the cold current from Davis Strait, the barren lands lie considerably south of it. In Norway and Lapland also temperate forests are found north of the circle, in North Russia the tundra extends well south of it. In the temperate zone, even near the tundra, the summer temperature is always high enough, and lasts long enough, to allow such plants as barley, oats, rye, flax, hemp, and beet to ripen. Situated in the heart of the land-mass of the north temperate zone are the **steppes**—great rolling plains covered with grass, famous for the cattle reared upon them.

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* *Anopheles* for malaria, and *stegomyia* for yellow fever.

These grass lands are mainly situated in South-east Russia to the north of the Caucasus, and in Asiatic Russia (Khirgiz Steppes) to the north of the Pamir. They are inhabited by nomadic tribes, who live in tents, and herd great flocks of sheep and cattle, driving them from place to place in search of good pasture.

Altitude.—In the same latitude climate varies according to the height of a region above sea-level. The summits of high snow-capped mountains have a dry and cold climate corresponding to that of the frigid zones. So that the progressive diminution of temperature due to ascent at any latitude above sea-level corresponds to the progressive diminution due to a pole-ward movement from that latitude. Fig. 62, which gives the gamut of vegetation in Switzerland, exemplifies this; for there is no more decisive test for types of climate than characteristic vegetation. In the figure, the vertical climatic zones of the Alps correspond to the horizontal climatic zones of Europe between latitude 42° and the Arctic circle. If a country has many and great differences of level it will enjoy much variety of climate; on low-lying, level land there is great uniformity of climate. Brazil, a country larger than the United States, contains lands at all elevations—grassy plains, high table-lands, and lofty mountains—and has

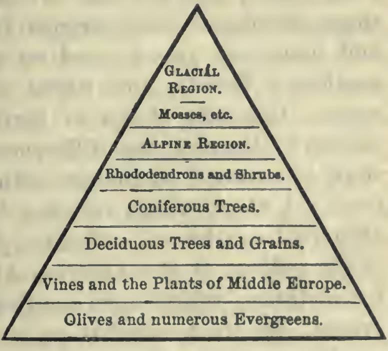
Glacial Region.
Mosses, etc.
Alpine Region.
Rhododendrons and Shrubs.
Coniferous Trees.
Deciduous Trees and Grains.
Vines and the Plants of Middle Europe.
Olives and numerous Evergreens.

Fig. 62.

consequently within its borders almost every type of climate. Mexico has three well-marked, vertical zones * of climate which pass gradually into one another. The lowlands along the coast, being hot and moist, are scourged by yellow fever; the hill-slopes, from about 3,000 to 5,000 feet, form the mild and dry temperate zone in which yellow fever does not occur; the high surface of the plateau is the cool zone. The low ground of the hot zone is covered with dense tropical forest, in the clearings of which sugar-cane, cacao, and bananas are grown; on the temperate slopes deciduous and evergreen forests occur, and tobacco and maize are grown; and on the cool lands are found coniferous forests, and wheat and barley are the chief crops. Opposite slopes of high mountain ranges have different climates, the difference depending upon which slope is exposed to the prevailing wind or to the sun's rays. A slope which receives both abundant rain and abundant sunshine is called the *favoured* slope. In those of the valleys of the Austrian Alps and the Carpathians, for instance, which open southwards the vine is largely grown. On the leeward slope of a mountain range, desert conditions often prevail. In general, however, the effect of altitude is much the same as that of latitude, *i.e.* the higher the altitude the colder the climate.

Distance from the Sea.—Water has a very high specific heat; therefore it rises in temperature very slowly and gives up its heat very slowly (see p. 24). During hot seasons the sea and other bodies of water become warm very slowly, because a great amount of heat is required to produce even a small rise in temperature. The result of the slow loss of heat is that at the end of a hot season there is a store of heat to be given up slowly during the following cold season ; the result of the slow gain of heat is that during the hot season the sea, being cooler than the adjacent land, gives cool breezes to that land every day. Hence seas and other large bodies of water tend to temper or modify the climate of islands and coastal regions. This property of water with respect to heat is quite different from that of land, and the difference gives rise to two distinct kinds of climate. Where a region is so near the sea that its climate is regulated by that proximity, the differences that occur between the temperatures of different hours of the day or between the different months of the year are very small. A small difference between the highest temperature of the day and the lowest temperature of the night is the daily range ; the same, or a proportionate, kind of summer and winter difference is the annual range. Proximity to the sea, therefore, produces a climate with a small annual range of temperature, that is, an **equable** climate, or, since such a climate is mostly met with in small islands, an **insular** climate.

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* Known as *tierra caliente, tierra templada,* and *tierra fría* respectively. Of course this zonal distribution differs considerably for the north and south of the country. It is best marked in the south, where the ascending physical "steps" are also best marked.

Insular Climate.—A good example of such a climate is afforded by the West Indies, which, except for the most of the Bahamas, lie wholly within the tropics. Latitude alone would give them a very hot climate, but the heat is modified by sea breezes and the north-east trades as well as by altitude. Thus Trinidad varies from 76° F. in February to 79° F. in September, and the variation between the summer and the winter mean temperatures at Kingston (Jamaica) never exceeds 5°. But on the Blue Mountains of Jamaica, whose highest elevation is about 7,400 feet, fires are often welcome, just as they are at the hill-station of Ootacamund in the Nilgiris, which lies only 11 degrees north of the equator. On the other hand, latitude alone would give Norway a cold climate, but as the country lies on the west side of the peninsula, it gets the benefit of the genial, moist, south-west winds and of the warm Atlantic drift. The Swedish coast has no such advantage as this; indeed it is swept by cold north-east winds. Hence the Norwegian harbours are open all the year round, while the Swedish harbours are frozen for six months of the year.

Continental Climate.—In those regions (outside the tropics) that are far away from the modifying influence of the sea, both the daily and the annual range become very great. A climate with a great range is called **extreme,** or, as it is usually found in the interiors of continental masses, **continental.**

The following set of figures will illustrate the difference between continental and insular climates:

	Latitude.	Mean Winter Temp.	Mean Summer Temp.	Range.
Iceland	65° N.	30°	45°	15°
Lena Valley (Siberia) . .	65° N.	– 50°	65°	115°
Valentia (Ireland) . .	52° N.	45°	60°	15°
Nerchinsk (S. Siberia) .	52° N.	– 25°	72°	97°

In fact, the whole of Asia, except the monsoon regions, has a continental climate; the monsoon regions, being within the tropics, have a very hot and moist climate. On the Iranian plateau in summer the highlands are bitterly cold, while in the valleys and lowlands the heat is suffocating. Siberia has of all countries in the world the most continental climate. The whole of the great plain slopes towards the north, away from the sun. Therefore during the long winter Siberia is swept by the freezing polar winds and kept from warm southern influences by the tablelands of Central Asia, and during the short summer it receives the full effect of the northern summer sunshine and becomes intensely hot in places. In winter the mercury in the thermometers freezes, in summer the land surface is in places almost too hot to walk on. The palm for extremes in temperature is taken by Verkhoyansk, a town in Siberia within the Arctic circle and about 400 miles northward of Yakutsk. The winter minimum has been taken as low as −88·8° F. (January 1886); the summer maximum has been recorded as high as 110° F., a range of nearly 200°. The −88·8° just mentioned is the lowest natural temperature ever yet registered, hence Verkhoyansk is known as the "pole of maximum cold." In North America the climate is mostly more continental than in corresponding European latitudes. This is due partly to the fewer great inland seas, and partly to the fact that the south-west trades from the Pacific are kept by the Rockies from reaching the eastern plains, which have a climate of a most pronounced continental type.

Annual Range of Temperature.—The annual range of temperature depends upon latitude and elevation as well as upon proximity to or distance from the sea. The annual range of London is 25°, Edinburgh is only 20°, Moscow is 50°, Yakutsk, the capital of Siberia, has a range of 110°, and Samoa, the island home of the late Robert Louis Stevenson, has a range as small as 5°. In the temperate zones a range of 15° to 20° would be considered equable, 60° to 90° extreme, and 20° to 40° fairly equable. In the tropics, a range of 30° would be considered extreme, a common range being about 5°. It should be noted that the mean annual temperature at any place is no guide to the climate. The mean temperatures both of summer and winter are necessary in order to know the range.

	Mean for year.	Mean for Jan.	Mean for July.	Annual range.
Greenwich . . .	50° F.	39°	63°	24°
Saratov	42° F.	14°	71°	57°

The first column would seem to indicate that Greenwich and Saratov had about the same sort of climate ; but the other figures show the true state of the case.

Prevailing Winds.—On-shore winds are always warmer than off-shore winds in the same latitude. The warm surface water of the ocean is blown on-shore by the prevailing wind of that region, and the cooler water comes up from the deeper parts cooling the off-shore wind (see p. 310). The east coast of Africa, for instance, is warmer than the west coast, because the west coast has for its prevailing wind the north-east trades and the south-east trades, which on that coast are off-shore winds ; whereas on the east coast the same winds are on-shore. This effect is most marked in temperate regions in winter, when the surface-waters of the sea are warmer than the land. It is for this reason that, in winter, the whole west coast of Great Britain is much warmer than the east coast. On-shore winds not only bring warm current-water to the coasts, they are also the rain-bearing winds, and the condensation of water as rain and its fall through the air have an important modifying effect upon climate. During condensation of the water-vapour into rain, latent heat is set free to raise the temperature of the air (see p. 25). Hence, the warm climate of certain coastal regions is partly due to the on-shore currents, and partly to the rains brought by the on-shore winds. The exception to the rule of on- and off-shore winds and currents occurs where a cold polar current flows parallel with and close to a longitudinal coast equatorwards. Such a case occurs along the coast of South Chile, where the icy Antarctic Drift is flowing northwards. This drift, even near the equator, has a temperature 20° lower than the surrounding waters. The Arctic current along the coast of Labrador, known as the "cold wall," is a similar exception to the rule (see p. 282).

Direction of Mountain Chains.—This and the following paragraphs deal with factors of climate of some importance, but not of chief importance. Mountain masses, if lying across the path of a prevailing wind which arrives moisture-laden, intercept these winds and cause them to rise, expand by relief of pressure, and give up their moisture in the form of rain. The mountains of Ireland, Scotland, and Norway exemplify this well. Mountain chains also afford shelter from winds : thus North Italy is protected from cold north winds by the Alps, the Mississippi basin, having no such protection, has severe winters, as also has South Russia for the same reason. Famous illustrations of the unprotected nature of the greater part of the United States are the great blizzard (see p. 174) of 1888 which killed 200 people in Dakota, and the blighting north wind which in the winter of 1885–6 seriously damaged the orange groves of Florida, far south though it is. But Florida lies just outside the protective screen of the Alleghany Mountains. Mountain chains intercepting rain-winds, if they are to have a beneficial effect, should not be too close to the coast of the country. It is unfortunate for Australia that the rain-condensing mountains lie so near the coast ; for the narrow coastal plain gets more rain than it needs, and when the rain-winds have crossed the mountains into the interior, the remaining moisture is re-evaporated by the great heat so that the interior has the driest of rain-shadows. In South America, on the other hand, the mountains are as far away as they can be from the on-shore coasts. Consequently all the country north of the Patagonian desert benefits by all the rain brought by the trade winds. The Iberian peninsula is a further example of coastal plains stealing all the rain. The eastern coastal plain receives the usual Mediterranean winter rains in abundance; the west and north-west coastal plains receive rain throughout the year and have mild winters. On the Meseta, in the interior, the climate is very extreme and specially dry, with a rainfall of less than 20 inches a year.

The Nature of the Soil.—Different soils and rocks have varying powers of absorbing and radiating heat. Sandy soil, for example, absorbs heat readily during the day, and radiates it just as readily after sunset, and thus regions like the Sahara experience an extreme daily range of temperature. It was the same phenomenon that so severely tried our soldiers in South Africa during the war of 1899–1902. Wet marshy ground lowers the mean temperature, because the water conveys the heat which it absorbs down into the ground. Holland, for example, is a country which is everywhere low and moist. Indeed, one-third at least of the surface is below sea-level. The climate of Holland is much affected by this lowness and the consequent dampness of the soil. Fogs and mists are very common, and ague is very prevalent. In fact, Holland amply bears out the truth of the old adage, "soil boggy, climate foggy."

Degree of Cultivation.—Forests growing at liberty tend to check free access of solar rays to the soil, prevent a free circulation of air, and thus favour a swampy, damp, and cool climate. The naturally growing forests on hill slopes serve to prevent rapid flooding of the rivers flowing down those slopes. The leaves and moss forming the "forest mat" form a sort of sponge which holds the waters back, as is the case with the Rivers Congo and Amazon, which are situated in a great forest zone. This is also true of vegetation of lesser growth than forest trees. So that it may be laid down as a dependable generalisation that much vegetation gives a moist climate, and little vegetation a drier climate. Where there is too great destruction of plant growth, not only is there no "mat" to hold back excess of rain waters, but the quantity of moisture in the air is reduced; for rain is always abundant where vegetation is plentiful, since foliage not only chills the moist air and acts as a rain-producer, but also helps to saturate the surrounding air by transpiration. The forest-covering on the hill slopes has another important effect: it protects the soil, holding it in its place, and preventing its removal by heavy rains. Hence, where forests have been stripped from mountain sides and from plateau tops, not only has the climate of the district been changed, but the top soil has also been removed and the underlying rock laid bare. The dry climate of Palestine is said to be in some measure due to the promiscuous deforestation of the country. The Seine floods are probably largely due to the wholesale cutting down of the forests on the Langres plateau, and the Rhone floods to a similar cause. The sudden flooding of rivers due to absence of vegetation is well exemplified in the Murray-Darling system of south-eastern Australia. Here the scarcity of all vegetation except brushwood allows the dried-up water-courses suddenly to become rushing and roaring torrents. In the Riverina district the floodings occur so suddenly that flock-masters find considerable difficulty in guarding their sheep against destruction.

Isotherms.—Lines drawn on a map connecting places having the same mean temperatures are called **isotherms,*** or equal-temperature lines.† The commonest isotherms found on maps are those of monthly and those of yearly average temperatures. The most interesting and instructive isotherm maps are those for the months of January and July, as they represent the average winter and summer conditions respectively. The isotherms are numbered to indicate the mean temperature of the places through which they pass. The Fahrenheit scale is the one used in the British Isles, and all temperatures are reduced to sea-level before being marked on the map. The allowance is 1° for every 300 feet of height above sea-level. Thus if the daily mean at the top of a hill 1,500 feet high were 40° F., 5° would be *added* to this, and the 45° marked on the map. If an isotherm map be studied, the first striking feature noticed is the way the isotherms curl about. Remembering that in high latitudes the water is warmer than the land, and that in the tropics the reverse is the case, the theoretical isotherms of the world may be diagrammatically represented (Fig. 63).

The isotherm of 32° is below the 60th parallel on land; but over the ocean, where the water is above the temperature of 32°, the isotherm has to bend towards the pole

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* N.B.—It is absolutely necessary that the student should consult an atlas in studying isotherms (*vide* Plate 6 in Meiklejohn's Comparative Atlas.)

† Isotherms and isobars have some affinity to contours. Contours are lines of equal heights, and so isotherms are lines of equal temperatures, and isobars lines of equal atmospheric pressures. Places at which the severity of an earthquake shock is of the same intensity may be joined by *isoseismic* lines, places having the same average rainfall by lines called *isohyets*, and places having the same average duration of sunshine by *isohēls*.

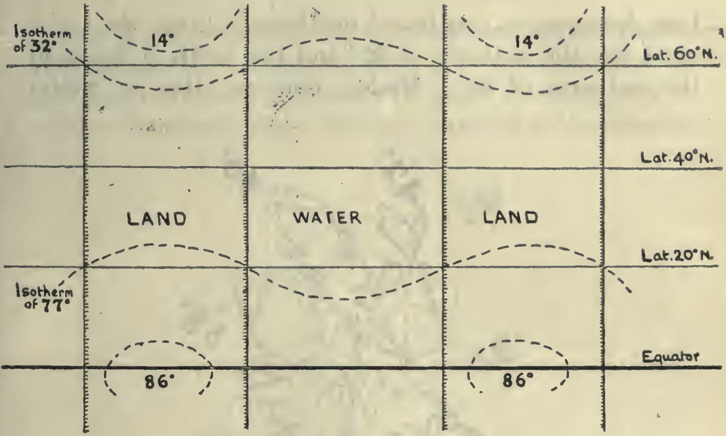
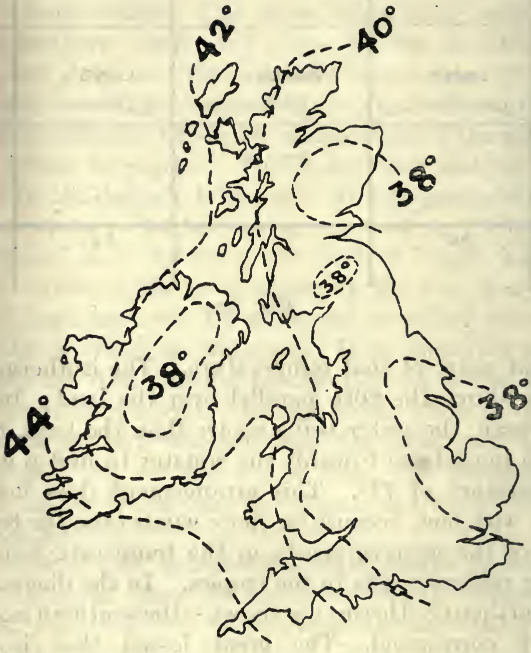


FIG. 63.

to find water of that temperature. The isotherm of 77° bends above the 20th parallel over the land; but over the ocean, the water being cooler than the land, the isotherm must bend towards the equator to find water at a temperature of 77°. This arrangement does not quite agree with fact, because on-shore winds raise the temperature of the western coasts in the temperate zones, and of the eastern coasts in the tropics. In the diagram only the northern isotherms are shown—the southern isotherms nearly correspond. The great lesson that isotherms teach is that *temperature depends upon other causes besides latitude.*

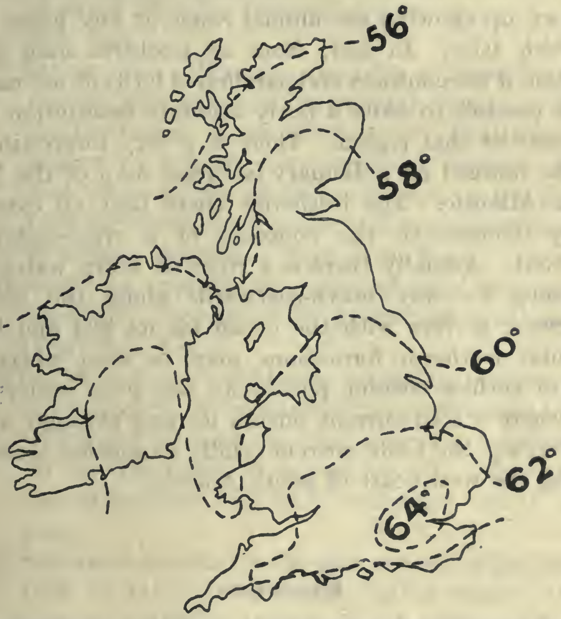
Isotherms of British Isles.—As an example of what can be read from isotherm maps, examine the January and the July isotherms of the British Isles. Notice first the contrast in direction. The January isotherms lie nearly north and south; those for July lie nearly east and west. From this you learn that in summer the average temperature decreases as you travel northwards, since the south coast has the isotherm of 62° and the north of Scotland the isotherm of 56°. Notice, however, that in winter



British Isles : Isotherms for January. The 38° *within the closed curve indicates a temperature of* 38° *and under.*

Fig. 64.

the whole of the west coast of Scotland has the same average temperature as the Isle of Wight (40° F.)—that is to say, average temperature in winter decreases not from south to north but from west to east. Not only so, but if you turn to a January isotherm map of Europe and follow the isotherm of 40°, you will find that the Shetland Islands have actually the same average temperature as Constantinople. In July, London is the warmest part of the British Isles, and the Outer Hebrides the coolest; in January, the south-west corner of Ireland and Cornwall are the warmest parts, and the east coast of Scotland and the Fen District the coldest. If you



British Isles: Isotherms for July. The 64° *within the closed curve indicates a temperature of* 64° *and over.*

Fig. 65.

follow the July isotherm of 60°, you will see that the east coast of England is warmer than the corresponding latitudes on the west coast. This is more pronounced in Scotland, as you may see by following the isotherm of 58°. From the two isotherm maps a table may easily be drawn up showing the annual range at any place in the British Isles. In fact, from an isotherm map of any region, if the contours and parallels of latitude are marked, it is possible to write a fairly accurate description of the climate of that region. There is a very interesting fact to be noticed on a January isotherm map of the North-east Atlantic. The isotherms there bear an extraordinary likeness to the contours of a river-valley (see p. 558). Actually there is a river of warm water there, pushing its way north-eastwards along the coast of Norway, a river with the ocean for its bed and banks. Similar isotherm formations may be seen wherever a warm surface current pushes its way over cooler water or where a cold current pushes its way through warmer water, *e.g.* the Chile current (chilly in another sense also) along the west coast of South America.

Exercises

1. Compare and contrast the climates of Cumberland and of East Yorkshire, explaining the reason for the differences observed. (Oxf. and Camb. Lower Cert.)
2. Compare the rainfall on the west and east of Great Britain with the rainfall on the west and east of New Zealand. In what wind belts do these countries lie ? How far can you explain similarities in the rainfall by similarities in the winds of

the two countries? (Oxf. and Camb. Lower Cert.)

3. Explain fully circumstances under which a region situated close to the sea-coast may be deficient in rainfall, and give an example of such a region, showing how it illustrates your answer. (Oxf. Sen. Loc.)
4. What are the differences between a typical oceanic climate and a typical continental climate? What are the causes of the differences? Illustrate your answer by reference to particular regions. Show that while on the whole the climate of the British Isles is oceanic, the continental type is approached in certain districts. (Oxf. Jun. Loc.)
5. Describe an arid desert region situated near to the sea-coast. Account fully for the deficient rainfall. (Oxf. Sen. Loc.)
6. What differences would you expect to find between the climates of countries in the temperate zone which are (*a*) near the east side of a large ocean, (*b*) in the heart of a continent? Account for the differences and give examples. (Oxf. Jun. Loc.)
7. Is it warmer or colder in the east or west of the British Isles at the same latitude, (*a*) in winter, (*b*) in summer? Why? Which are the least rainy parts of England? Why? (Oxf. and Camb. Lower Cert.)
8. Describe the climate of the "doldrums" (equatorial belt of calms) and compare it with the climate of the "horse latitudes" (sub-tropical belt of calms). (Oxf. and Camb. Lower Cert.)
9. What do you understand by the "Mediterranean" type of climate? Describe the positions of the chief

regions where this type prevails. What are the most characteristic products of those regions? (Oxf. and Camb. Sch. Cert.)

10. What part of Australia has a moist tropical climate? Explain how the climate comes to have this character, and give some account of the chief products of the region. (Oxf. and Camb. Sch. Cert.)
11. Vladivostok is in nearly the same latitude as Marseilles. Explain the difference in climate. (Camb. Sen. Loc.)
12. How do the climates of England, Newfoundland, and Manitoba differ from one another? What explanations can you give of the differences? (Camb. Jun. Loc.)
13. Explain fully, with examples, the following statement: "The climate of a country is affected by the position of its mountain ranges and the direction of its slope." (Civil Service.)
14. Explain and illustrate the following statement: "Extremes of temperature in summer and winter, as well as a low yearly average of temperature, distinguish the eastern side of the continent of Europe and Asia, as compared with its western side." (Civil Service.)
15. Account, as fully as you can, for the fact that the isothermal line which runs through London (lat. 51° 30′ N.) runs through New York (lat. 40° 49′ N.). If isothermal lines are drawn on the globe for the *winter* months (isochimenal), and others for the *summer* months (isotheral), point out some of the chief differences between the two systems of lines. (Civil Service.)
16. What is an isotherm? Explain how an annual

isothermal chart is constructed, stating what observations have to be made.

On such a chart of the whole world it is noticed that the isotherms run approximately in the direction of the parallels of latitude. Explain this fact, and state (with reasons) any marked exception to it that you know of. (Oxf. Sen. Loc.)

17. How do the direction of isothermal and isobaric lines alter in the northern hemisphere as we pass from winter to summer, and why? (Coll. of Preceptors.)
18. Why has Turkestan a hotter July temperature than Sumatra?
19. If the earth rotated from east to west, what would happen to the Sahara Desert?
20. Explain the terms: Mediterranean climate, sirocco, weather, antipodes, föhn effects, sea breeze.
21. From an inspection of a mean annual isotherm map of the world compare the following places with respect to latitude and mean annual temperature: Copenhagen and St. John's (Newfoundland), Edinburgh and Halifax, N.S., London and Philadelphia, Lisbon and Charleston, U.S.A. Give a reason for any striking differences.
22. Write short notes on the climate of the following parts of the world: Tasmania, Eastern Russia, Tibet, Iceland, Lombardy.
23. Divide North America north of Mexico into climatic regions, and point out the chief characteristic of each. (Oxf. and Camb. Lower Cert.)
24. What is meant by the *mean annual temperature* of a place? How is it determined from observations? Mention any place you know of which has a mean

annual temperature of about 40° F. (Oxf. Jun. Loc.)

25. What are the chief elements which influence the climate of a country ? Give examples in illustration of your answer. (Oxf. Jun. Loc.)
26. State and account for the chief characteristics of a land climate as regards variation of temperature, amount of rainfall, and distribution of wet and dry seasons. Give examples. (Oxf. Jun. Loc.)

CHAPTER XVI

Distribution of Rainfall

General Distribution.—We have seen that at the equator there is a belt of low pressure, at latitude 30° N. and S. belts of high pressure, at latitude 60° N. and S. other belts of low pressure, and at the poles other regions of high pressure. This arrangement gives the clue to the general distribution of the rainfall of the world. At the equator, because of the great capacity of the heated air for moisture, and owing to the rise of the heated air by convection (see p. 17), and to its expansion and consequent cooling, there is a belt of constant and heavy rains accompanied by violent thunderstorms. From this equatorial belt towards the poles there is a general decrease of rainfall. Near the equator the annual amount reaches hundreds of inches; in the temperate zones it reaches only to tens of inches. From the high-pressure belts at 30°, winds blow in both directions, towards the equator and towards the poles. Therefore any moisture in these winds is carried away from these belts, the calms of Cancer in the north and of Capricorn in the south. Furthermore, at these belts of calms the air is coming downwards towards the earth from the cooler regions of the upper air to warmer levels where it is able to hold more moisture, so that these belts are regions of little rain. In the temperate zones the bulk of the rainfall is due to the contact of the warm moist air of the westerly winds with the cooler lands over which they blow. On those coasts of the temperate lands where these winds are forced to ascend mountain slopes there will be specially heavy rainfall, often nearly as heavy as tropical rains. Seathwaite in Cumberland, Snowdon in Wales, and Coimbra in Portugal, for instance, have exceptionally heavy rainfalls.

Rains of the New World.—The important feature of the trades is that they are easterly—north-east north of the equator and south-east south of the equator. In the New World these winds are on-shore to the whole of Central America, the West Indies, Venezuela, the Guianas, and Brazil. In Central America these winds bring rain to the eastern slopes of the plateau of Mexico and to those of the central ridge farther south all the year round. The western slopes in winter get nothing more than a very dry rain-shadow, in summer the south-east trades blow nearly south-west near the west coast,* becoming on-shore winds and bringing sufficient rain to prevent that coast from becoming desert. In Venezuela, Guiana, and Brazil both the trade winds, warm and wet, are blown from the equatorial Atlantic into the Amazon basin. There they give up their moisture to the highlands north and south of this basin to the extent of over 100 inches a year. The eastern slopes of the Andes extract the last drop of this moisture, so that the winds are absolutely dry when they reach the western slopes, and a large part of the Pacific coast is desert.

Rains of the Old World.—In the Old World the north-east trades are an off-shore wind to the west coast of Africa north of the Sudan, and although on the opposite

* A rainfall map of the world *must* be consulted during the reading of this chapter (*vide* Plate 7 of Meiklejohn's Comparative Atlas).

side of the continent they are an on-shore wind, they bring no moisture because they blow over southern Eurasia, and therefore the region north of the Sudan is a desert. The south-east trades are an on-shore wind to the southern coast of East Africa; but during the southern winter they are so drawn into the current of the south-west monsoon that they give up a very uncertain quantity of rain to Africa, the east coast of Madagascar and the district round Zanzibar being the only parts that benefit to any great extent. During the southern summer, however, the north-east monsoon winds press down upon the south-east trades and force them into South-east Africa. They give copious rain to feed the Nile and the Congo head-waters and the Zambesi, but are quite dry when they reach the Desert of Kalahari. On the west coast of Africa the south-east trades blow back from the south-west during the southern winter into the shores of the Gulf of Guinea and carry their rains across the continent as far as the mountains of Abyssinia. South of the Gulf of Guinea the south-east trades are entirely off-shore, which further accounts for the barrenness of the Kalahari region. Walfisch Bay is said to average one-third of an inch of rain per annum. The monsoon region of southern Asia has already been dealt with under winds (see p. 155). In South-east Asia the north-east trades blow during the northern winter, almost ignoring the Siamese peninsula, but giving abundant rain to the East Indies; then passing over these islands they turn and blow as a north-west monsoon, bringing rains to the north of Australia. During the northern summer the north-east trades become the south-east monsoon and give to China and the Siamese peninsula plentiful rains. But not one vestige of moisture from either the south-west monsoon blowing across India or the south-east monsoon blowing across China ever reaches the Desert of Gobi. Persia also receives a minimum quantity of rain, for its prevailing winds come from the south-west across African and Arabian sands, or from the continental land-area of the north-east. To supply the want of a sufficient rainfall the peasantry have devised a wonderful system of underground irrigating canals. Arabia obtains what little moisture it enjoys from the south-west monsoon. But only the lofty highlands receive enough rain to feed intermittent torrents and, in a few cases, permanent streams. Moreover, the south-west monsoon, having just traversed or at least skirted the African continent, has been robbed of most of its moisture. The central districts of Arabia are mainly rainless deserts.

Northing and Southing of the Doldrums.—During the northern summer the line of maximum heat, or thermal equator, lies considerably north of the geographical equator, because in the northern hemisphere land-surface preponderates; during the southern summer it lies slightly south, because in the southern hemisphere water-surface predominates. The whole system of planetary winds moves with this movement of the thermal equator, and the movement is sometimes spoken of as the "northing and southing of the Doldrums." It is the northing of the doldrums during the northern summer that turns the south-east trades into the Gulf of Guinea and towards western Central America. This northing also moves the Amazon rainfall slightly northward and gives abundant rains during the northern summer to the *llanos* of the Orinoco; the southing that follows during the southern summer diminishes considerably the rainfall of the Orinoco, but gives correspondingly more to the Amazon and to the Paraná.

Rainfall of the British Isles.—On the whole, the rainfall of the British Isles diminishes from west to east. The reason of this is threefold. (1) The islands lie in the belt of the south-westerly anti-trades, which reach them directly from the ocean. (2) The track of cyclonic storms lies nearer the west coast than the east. (3) All the chief highlands lie near the west coast. In Ireland, because of the absence of extensive areas of highland, there is a more uniform distribution of rain than in any other part of the islands. The south-west corner of Kerry and Cork and the hills of Connemara receive from 60 to 70 in. per annum,* Galway over 50 in., and the west of Ireland generally from 40 to 50 in. The centre and east receive from 30 to 40 in., and Dublin 30 in., the lowest rainfall of the country. In Great Britain the western Highlands of Scotland and the Cumbrian mountains of England average 80 in. a year. This average is exceeded in a few spots such as Ben Nevis (4,406 ft. above sea-level) at whose summit the registered average is 130 in., and Seathwaite in Cumberland where the average is 131 in. In both these cases the heavy average is due to altitude, since at Fort William, which lies at the foot of Ben Nevis and only 29 ft. above the sea, the average is only 77 in. North Wales round Snowdon averages over 80 in., most of middle Wales from 55 to 60 in., and scarcely any part of the Principality averages less than 50 in. The uplands of Devon and Cornwall average 45 in. a year. The Pennine Chain averages 40 in., while parts of North Lancashire on the windward slopes of these hills and south of the Cumbrians have an average of from 45 to 50 in. On the east of Scotland and over the whole of the English plain the rainfall is never above 40 in., and east of a line drawn from Montrose through Dundee, Alloa, Flodden, Durham, Stockton, Hodsock, Leicester, Oxford, and Tunbridge Wells to the south coast at Beachy Head it is everywhere under 30 in. The driest part of the islands is Lincolnshire (except on the Wolds) and the Fen District, which have an average of less than 25 in. There is no seasonal rainfall in the British Isles, as the rains are fairly evenly distributed throughout the year, a distribution that characterises the West European climate. [Winter rains characterise the Mediterranean climate, and small rainfall with most rain in summer characterises the extreme climate of eastern Europe.] December and January are the wettest months in the western districts, where the average rainfall is high; in other parts October is the month of most rain. The British Isles may be divided into four parts by two straight lines drawn from Cape Wrath to the Isle of Wight and from Galway to Grimsby. The N.W. quarter is the cool rainy region, the S.W. quarter the warm rainy region, the N.E. quarter the cool dry region, and the S.E. quarter the warm dry region.

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* A rainfall map of the British Isles *must* be consulted while reading this section.

The following table illustrates the variation of rainfall in inches on the west and east of the British Isles:

Galway .	52	Penzance .	42	Skye .	103
Dublin .	30	London .	25	Aberdeen .	30

The varying incidence of the rain from the south-west winds is illustrated by the rainfalls of:

Newport .	50	Chepstow .	35	Tewkesbury .	27

Rain and Great Rivers.—Every river which rises within the tropics annually overflows its banks. The incessant torrents of rain which attend the vertical sun swell these rivers and flood the low-lying lands. This is the case with the Amazon, the Paraná, and the Nile, and in fact with every considerable river whose source is not far from the equator. The annual summer flooding of the Nile occurs after the heavy spring rains in Abyssinia which are brought by the north-east monsoon and the south-east trades (see p. 229). These spring rains do not reach Egypt till months after they have fallen in Abyssinia. The Congo receives its flush of flood waters at the same time from the moisture-laden south-east trades, and except in very dry years it also receives the overflow from Lake Tanganyika through the Lukuga River. The Amazon, though not the longest river in the world, carries a greater volume of water to the sea than any other river, because it is fed by tropical rains alternately from the northern heights at the northing of the doldrums and from the southern heights at their southing. The Ganges receives its constant supply of water from the snows of the Himalayas which descend as glaciers to about 13,000 ft. above sea-level. From the snout of one of these glaciers issues the head stream of the river, from another the companion stream the Jumna, and from others the left-bank tributaries. But over and above this glacial feed, the river receives summer flood waters from the south-west monsoon rains. And because of its never failing it is to the Hindus a holy river and by them worshipped and honoured. The Mississippi is not a tropical river. It rises in Lake Itasca at a height of only about 800 ft. above sea-level. The long tributary the Missouri flows from the Rockies, and the large tributary the Ohio from the Alleghany plateau. These rivers flow through an area of small rainfall, and their volumes are small compared with their length and with the bigness of their drainage area. The north-east trades give no rain to the Pacific coast, being off-shore winds. The south-westerly anti-trades give over 60 in. of rainfall on the Pacific side of the Rockies, but on the eastern slopes the same wind feeds the Missouri, the Red River, and the Arkansas with only 10 in. per annum. But during the northern summer the north-east trades that blow across the Atlantic swing round in the Gulf of Mexico and blow up the Mississippi Valley, contribute something to the rainfall of the western plains, and give to the Appalachian belt a rainfall of from 50 to 60 in. a year.

Rainfall and Agriculture.—In temperate climates a rainfall of less than 12 in. per annum produces semi-desert conditions, *e.g.* the steppes in South-east Russia near the Caspian, and the Khirgiz Steppes at the foot of the Pamir Plateau. With a rainfall of 12 to 20 in. grass will flourish sufficiently well for grazing purposes ; with a rainfall of over 20 in. agriculture becomes possible. Within the tropics the best average is between 30 and 60 in., above 80 in. vegetation becomes too luxuriant and rank. In the British Isles the wheat harvests are found to be best when the previous autumn rains were not too heavy, the following winter frosts not too severe, the following spring cool and fairly wet, and then a dry summer. During a period of 30 years from 1854 to 1883 it was found that when the yield of wheat was above the average, the rainfall of the previous autumn was below the average and that further rains came in the late spring and early summer. In Mediterranean regions the winter rains and hot summers seem to be very favourable to prolific fruit crops, and these regions are usually wine-producing countries. The late spring and early summer rains of North America are very favourable to the growth of wheat and maize. The Argentine wheat crops and those of South Russia also depend upon late spring and early summer rains. In the tropics the great heat and moisture favour easy cultivation of maize, millet, rice, and tea. Rice requires abundant heat and moisture, and the rice-fields must be regularly flooded, if not by rain-floods, then by irrigation. Tea also requires abundant rains, but unlike rice, it does not thrive if water gathers and remains about its roots. Hence the tea-plant is cultivated (*e.g.* in Assam and Ceylon) on the rainiest slopes of the hills, not only so that it may receive the heavy rain-supply it needs, but also so that the rain may run off the fields rapidly. Where rainfall is evenly distributed through the year, as in western Europe north of the Pyrenees and the Alps, root crops—such as potato, beet, turnip—and flax and hemp grow well. But in these regions if the summer rains are too heavy, the crops rot in the ground. In sheep-grazing countries such as South Australia and New South Wales it has been found that with under 10 in. of rain per annum only 10 sheep to the square mile can be reared, with 15 in., 100 sheep can be reared on each square mile, while with over 20 in. it is possible to graze profitably over 600 sheep to the same area. On the pampas of South America it was found that with 35 in. of rain 2,600 sheep could find plenty of food on each square mile.

Deserts.—The name desert properly applies to the frozen polar wastes as much as to the sandy tropical and sub-tropical wastes. So also, the snow-clad summits of high mountains and plateaux are, strictly speaking, deserts. But the usual connotation of the term is wide wastes of comparatively low-lying land barren for want of rain. That is, there is scarcity of water on the surface and scarcity of moisture in the air. From a rainfall map of the world which gives the annual rainfall, the desert regions may be quite easily picked out, as they correspond to the regions of minimum rainfall. If on such a map lines are drawn (*isohyets*) connecting those places that have the same annual rainfall, the deserts may be more accurately located. The latitude limit must be fixed at about 50°, as beyond that, the barrenness of the land is due to frost and snow. The hot deserts will be found to lie within the 10-in. isohyet; the region from the 10-in. line to the 5-in. line may be regarded as desert border or sub-desert; within the 5-in. line lies the desert proper; and outside the 10-in. line desert conditions do not prevail. The largest deserts of the world are those lying in the trade-winds belt. Professor Davis says: "Low lands over which the trade winds blow are made desert by the drying action of their warm air. The Sahara and the central Australian deserts are thus explained." The same explanation holds good for the Arabian and for the Great Indian deserts. The deserts of Persia, Turkestan, and Gobi are in the belt of the anti-trades, and are subject to the influence of the pressure systems that bring about the monsoonal changes in southern Asia. In the northern summer when the centre of low-pressure system lies in the south-east corner of Persia, cold dry winds are drawn down *into* the desert region from the north, and moist winds are drawn *towards* the desert region from the Indian Ocean; but as all the moisture is given up to the western Ghats, the Himalayas, and the mountains of Burmah, the desert region receives no more benefit from these winds than from those from the north. In the northern winter when the centre of high pressure lies just south of Lake Baikal, the winds blow *from* the desert region in all directions. Thus, in summer no winds arrive but dry winds, and in winter no winds arrive at all. Hence the broad belt of desert stretching across Asia from Arabia nearly to the Pacific Ocean. The Great Basin of the Rockies is served in precisely the same way, as is also the Gila Desert in the West Colorado basin. The Atlantic N.E. trades swing round in the Gulf of Mexico and blow up the Mississippi valley and into the desert valleys, but after they cross the mountains of New Mexico, there is no moisture left for either the Gila basin or the Salt Lake basin. The Pacific trades do not blow towards these regions at all. The desert of Atacama in Chile on the Pacific side of the Andes is explained in the very same way.

Desert Climate and Vegetation.—The climate in deserts is exceptionally extreme. The annual range is as much as 90° F., the daily range is sometimes even greater, extending from 150° F. during the day to below 32° F. during the night. Agriculture is, of course, possible only in the spots called **oases**, where a spring bubbles up through the sand, and in those parts where irrigation can be employed. The characteristic tree of these oases is the date palm, and most of our dates come from desert or semi-desert regions like the country round Baghdad and certain Saharan oases. Absolutely plantless areas are comparatively few, and they exist only among the moving sand-dunes and in the stony places. There is a vegetation that is able to suit itself to arid and extreme desert conditions, just as mosses and lichens suit themselves to the cold desert conditions. The chief are the cactuses and the spinifex or porcupine grass. The general name for desert vegetation is **scrub**, and scrub-land is always found bordering the sand-deserts of the world. These desert plants are characterised by coarse, hard, glazed surfaces of both stems and leaves, which allow the minimum exhalation of the hardly won moisture.

Desert Irrigation.—The desert-lands require nothing but water to become fertile, and artificial supplies are sometimes transported to parts of the deserts by means of canals if there is a river sufficiently near to serve as a main supply. Extensive works intended for the irrigation of large districts existed in times of remote antiquity in Mesopotamia,* Persia, India, and China, and where such works still exist the countries have not entirely lost their ancient prosperity. For the irrigation of any large area main canals have to be cut to supply innumerable branch canals through an incredible number of sluices, and these canals catch, regulate, and distribute the water from some main supply, usually a river. In Upper Egypt there are thousands of these canals at work, many of them extremely old and of great interest. The Bahr-el-Youssouf ("Water of Joseph") is said to have been constructed under the orders of Joseph, Pharaoh's viceroy in Egypt. It runs parallel to the Nile for 140 miles along the left bank. The underground canals of Persia enable the tobacco plant to be cultivated in that country. The dry Punjab in India is admirably irrigated by water taken out of its various rivers, and excellent wheat is now regularly raised from lands where formerly little but semi-desert conditions prevailed, and the Buckingham Canal renders the Coromandel coast fertile. In the different States of the Australian Commonwealth, which have, on the whole, a dry climate, irrigation, both from artesian wells and impounded river-water, has been conspicuously successful.

EXERCISES

1. It is found on the whole the greatest annual rainfall occurs near the equator, and the amount is less the higher the latitude.

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* The ancient irrigation systems of Mesopotamia were in 1914 being revived, and already some thousands of acres that have been lying waste for centuries have been brought within reach of the Arab cultivators.

How do you account for this ? Mention any important region which forms an exception to this rule, stating how and why it deviates from the rule. (Oxf. Jun. Loc.)

2. Select *one* of the hot desert regions of the world. Describe its position. Account for the deficient rainfall. Name any useful products obtained from it.
3. Distinguish between a "maritime" and a "continental" climate. Select two places in about 50° north latitude the climates of which differ considerably, and account for the difference.
4. Describe the positions of two regions situated within the tropics, one of which has one very dry and one very wet season in the year, and the other no special seasons of intense drought or excessive rainfall.

   Account for the climate of each region named. (Oxf. Sen. Loc.)
5. The annual rainfall at Carmarthen is 49 inches, and at Greenwich 23 inches. Explain what is meant by the statement, and account for the difference. (Civil Service.)
6. Between latitudes 35° N. and 30° S. the driest climates are usually found on the *west* sides of mountains or high land, while in higher latitudes this is usually the case on the *east* sides. Explain this and give examples. (Oxf. and Camb. Lower Cert.)
7. Describe and account for the main features of the distribution of rainfall in India during the north-east monsoon. What part of India receives the bulk of its rainfall during the north-east monsoon ? What are the chief crops produced in that region ? (Oxf. and Camb. Sch. Cert.)

8. Describe the main features of the rainfall of the British Isles. Where are the wettest and driest regions ? Which are the seasons of the greatest and least rainfall ? Give reasons to account for facts. (Oxf. and Camb. Lower Cert.)
9. What parts of the world receive fair or heavy rains in the winter half-year but hardly any rain in summer ? Explain this. Point out how this affects the vegetation. (Oxf. and Camb. Lower Cert.)
10. Give examples (one of each type) of regions (*a*) with summer rainfall, (*b*) with winter rainfall, (*c*) with rainfall at all seasons of the year. In each case give what explanations you can. (Civil Service.)
11. Mention examples of regions which have a large rainfall (over 70 inches per annum). What explanation can you give of each example ? (Camb. Jun. Loc.)
12. Explain exactly what is meant by the statement, "The average rainfall of the Thames basin is 26 inches." What are the chief causes which determine the distribution of rain ? (Coll. of Preceptors.)
13. Name three very wet and three very dry regions of the earth, and state in each case the cause of the prevailing condition.
14. What are the conditions which may determine the annual rainfall of a district ? Illustrate your answer by reference to districts with a very low and others with a very high rainfall.
15. Draw and describe a rain-gauge. Why is the water of a rain-gauge transferred to another vessel for measuring ? What is meant by an inch of rainfall ?

16. What is a *rain-shadow*? How is it produced? Give examples from continental Europe. (London Matric.)
17. From the examination of isotherm and rainfall maps establish the connection between range of temperature and distribution of rainfall in the Iberian peninsula.
18. Why is the rainfall on the north side of the Khasia Hills so much less than on the south side?
19. State which parts of England get the most rainfall during the year, and which parts get the least. Give fully the reasons for the difference. (London Matric.)
20. The mean annual rainfall at Glasgow is 40 inches. Explain fully the meaning of this statement.

    State the districts in Scotland which have the greatest and least annual rainfall, and account for the facts. (Oxf. Jun. Loc.)
21. The area of the funnel of a rain-gauge is 24 square inches, and after a rainstorm 6 cubic inches of water were found in the vessel. What rainfall was represented by the water collected?
22. What causes determine rainfall? Why have some places more rain than others, and at a different time of the year? Give examples from any part of the British Isles or Europe. (Coll. of Preceptors.)
23. Why has Lancashire more rain than Yorkshire and Argyllshire more than Lancashire?
24. Why is Biarritz one of the rainiest places in France?
25. Show how rainfall affects the distribution of population in Africa, and explain also why Morocco is more fertile than Tripoli.
26. Why does Australia receive most of its rain from the east and New Zealand most of its rain from the

west? What part of New Zealand receives rain from the east, and when?

27. Why are December and January the wettest months in the west of the British Isles, and August the wettest month in the east?

28. At what season of the year does the greatest amount of rainfall take place in the greater part of the Indian Empire, and to what is the rainy season due? Can you mention any exception to the general rule? (Oxf. and Camb. Lower Cert.)

PART III

THE HYDROSPHERE

CHAPTER XVII

The Oceans

The Formation of Oceans.—It has been shown (see p. 63) that our earth in its early stages was in a very heated state, and that as time progressed it underwent a cooling process. The effect of this cooling has been to cause contraction. The cold outside shell does not shrink; but as the interior diminishes in size, this crust becomes wrinkled in a manner that may be compared with the wrinkling of the skin of an apple which is drying. Hence the exterior *crust* crumples to fit or accommodate itself to the shrinking core, and the crust thus becomes distorted. This distortion is the cause of depressions and elevations being formed on its surface. The depressions have in time been partially filled with water received directly and indirectly from the surrounding atmosphere. Some of the expanses cover large areas and are called **oceans**; others, of lesser extent and almost surrounded by land, are termed **seas.** The proportion between land and water works out approximately to a ratio of 1 : 2·43. This calculation is based on the assumption that a great land mass surrounds the South Pole—an assumption which recent Antarctic expeditions have verified. To this land mass the name of Antarctica has been applied. The North Pole, however, is completely surrounded with water, and to this water we give the name of the Arctic Ocean.

The Formation of Seas.—The Arctic as well as the other oceans has seas which may be divided into two classes: (i) those almost wholly enclosed and only connected with the ocean by one or more narrow passages of water termed straits, (ii) those partially enclosed and generally separated from the ocean by a group of islands. In the first case the origin of such seas may be attributed to the subsidence of the land and the overflowing of the depression thus formed by the waters of the ocean. In the second case two agents may have been at work: the land may have subsided, but the effect of the force of the ocean water may also have aided in breaking through and carving out for itself a series of more or less wide passages. The North Sea provides us with an excellent example of the work of both agents. In most seas gulfs are to be found. These have been caused by fractures of the earth's crust or by the sea overflowing subsided land. While the Gulf of Genoa and the Bay of Bengal are examples of the former class, the Bay of Fundy provides us with an example of the latter. Sometimes a gulf is formed by both agents. One of this kind is the Bay of Biscay. Although the earth's crust has reached a stage when the moving process no longer seems to continue, it must not be assumed that this action is at an end. On the contrary, many parts of the earth's surface are now undergoing a process of gradual upheaval, while others are subsiding. The west coast of Scandinavia is slowly rising, whereas the east coast is gradually subsiding. The ocean floor, like the land mass, is subject to like changes, and the effect of these is to cause variations to take place in the depths and shapes of the large seas and oceans.

Relation of Land and Water.—Almost four-fifths of the whole area of the earth's surface is covered with water. The distribution of land and water is not, however, uniform. Examine a map of the world, and you will observe that nearly all the large land masses of the globe lie north of the equator, while a very large percentage of the area south of this line is composed of water. Except for Australia, South America, and Africa,

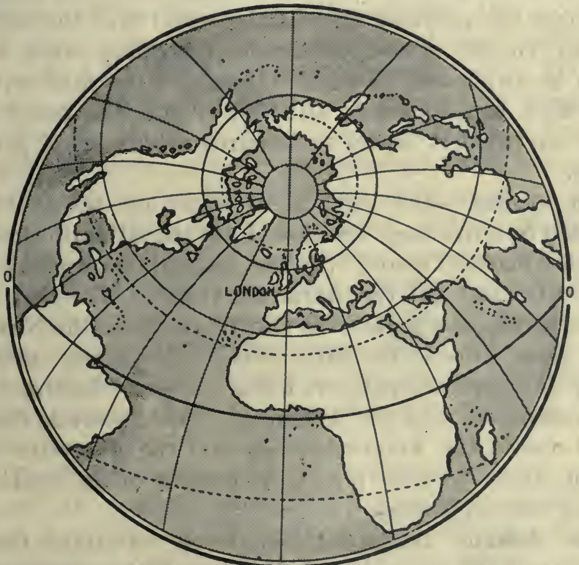

FIG. 66.

a large belt of water encircles the southern hemisphere. Of this expanse, that lying between 35° S. and 60° S. latitude is called the Southern Ocean.

The world may be divided into two great divisions—namely the **water hemisphere** and the **land hemisphere.** Of the water hemisphere the pole is near New Zealand, but near the pole of the land hemisphere stands London (fig. 66), the greatest city in the world and the capital of an empire whose dominions are flung wide over both hemispheres. Note that much of the land within the land hemisphere is situated within the temperate zone, and that it tapers southwards in a series of peninsulas.

The Oceans.—The expanse of water on the globe is divided into five large divisions : (1) the Atlantic Ocean ; (2) the Pacific Ocean ; (3) the Indian Ocean ; (4) the Arctic Ocean ; (5) the Antarctic Ocean. The first two of these oceans separate the Old World from the New on both sides. For us the Atlantic Ocean has always proved of great interest, because it forms the great highway for our commerce with the Americas. The Antarctic Ocean lies between the Antarctic circle and the Antarctic continent, and its waters mingle with those of the Southern Ocean which encircles it.

The Atlantic Ocean.—Although the Atlantic Ocean is only half the size of the Pacific, it is the most important of all the oceans on the surface of the globe, for it is a sea-canal between the Old and New Worlds. It has a longer coast-line, with more and larger inland seas, bays, and gulfs ; its shores are bordered by more fertile countries ; and hence it has always possessed a far larger commerce than any other ocean. Its shape is like the letter S—a longitudinal valley, a long, winding belt of water running through three zones. Both sides of this ocean are rich in islands, more especially the west side; and the West Indian Archipelago is surpassed only by the island-world of the East Indies. The waters of the Atlantic cover an area of 33,000,000 square miles—that is, nearly one-fifth part of the globe's surface. On its northern and southern sides it is open to the cold waters of the Arctic and Southern Oceans respectively, but it is bounded on the east by Europe and Africa, and on the west by the Americas. Into each of these land masses it sends forth small and large branches. The American continent is almost cut in two by the Gulf of Mexico and the Caribbean Sea, while the indentations in the European continent are even more pronounced. Here we find the Mediterranean Sea (the largest enclosed sea in the world), the Bay of Biscay, the North Sea, and the Baltic Sea. In Africa the Gulf of Guinea also covers a large extent. A much larger amount of river-water flows down into this ocean than into any of the others, its drainage area being almost 10,000,000 square miles. It is from the two Americas that it receives the largest contributions, the greatest valleys in that hemisphere sloping down towards it.

The Pacific Ocean.—This ocean has the largest area of any. It extends over about 55,000,000 square miles, and is remarkable for the many islands, both continental and oceanic (see p. 340), which dot its surface. In shape, it is an immense oval basin, which contracts towards the north, and which has its greatest breadth on the equator. Its coasts are very regular, with few indentations; and hence its coast-line is comparatively short. It is of great depth, and has the Asiatic coast much more highly developed than the American. The most important indentations are the Sea of Okhotsk, the Japanese Sea (one of the deepest enclosed seas in the world), and the

China Sea. Its American coast presents a striking contrast to the Asiatic. There, the only indentations of importance are the submerged valley called the Gulf of California and the numerous fiords along the submerged (or "drowned") mountainous coasts of Canada and Chile. On the south the ocean is open to the cold waters of the Southern Ocean, but on the north it is sheltered by land masses which project from the Asiatic and American continents. Bering Strait—a narrow passage of water—alone connects it with the Arctic Ocean. It is girt by an almost unbroken belt of volcanic activity known as the "Girdle of Fire" (see p. 378). The river-drainage of the Pacific is, in proportion to its size, remarkably small. This is in no small measure due to the very mountainous coast of the American continent, through which it receives only a very small contribution of water. The drainage area that contributes water to the Pacific is only about 8,500,000 square miles, and it is mainly from the Asiatic slopes that the ocean receives its chief supply. Australia, like America, sends forth very few rivers, which are for the most part only small mountain-torrents. The commercial importance of this ocean and that of the Atlantic will rapidly increase now that the Panama Canal has been opened.

The Indian Ocean.—The Indian Ocean, "the region of the monsoons" (see pp. 154–6), lies mostly in the southern hemisphere, within the torrid zone, and between the three continents of Africa, Asia, and Australia. Its area is about 17,000,000 square miles. Unlike the Atlantic Ocean, it is land-locked on the north. To the south it presents an open front to the waters of the Southern Ocean. Like the Pacific, it sends forth many branches into the Asiatic continent, the chief of which are the Red Sea, the Persian Gulf, the Arabian Sea, and the Bay of Bengal. A noteworthy fact is that there are no openings of any size either along the West Australian or East African coasts. It possesses a very large drainage-basin, and several of the largest rivers in the world bring to it their contributions. Most of this supply is brought down by the rivers of Asia. The Red Sea receives no large river, and the Persian Gulf only one, the Shat el Arab. The Indus, the Ganges, the Brahmaputra, and the Irrawaddy with their affluents carry down to the sea the melted snow from the highlands of the interior of the continent. Comparatively little water is contributed either by the African or Australian rivers. Like the Atlantic and Pacific, the Indian Ocean is an important highway of commerce.

The Arctic Ocean.—This ocean is connected with the Atlantic by a broad opening, and with the Pacific by a very narrow one. It has one important branch, the White Sea, which penetrates for some considerable distance into northern Europe. This sea is blocked with ice for many months during the year, because it is shut off by the Scandinavian Peninsula from the warm waters of the Atlantic Drift. The drainage area of the Arctic is also considerable. Numerous large rivers send down into it an enormous supply of fresh water, from the Siberian Plain, the north of Europe, and the great northern plain of North America. The whole ocean is almost entirely covered by ice-fields which vary from 5 to 50 feet in thickness. Round the coast are many islands, of which Greenland is the largest. On the west coast of Greenland are numerous glaciers, the best known of which is the Humboldt Glacier, in 79° north latitude. When these glaciers reach the sea, the ends break off under the lifting swell of the waves ; and these broken ends form icebergs (see p. 477). This process is called the "calving of the glaciers." The waters of the Arctic have been found to be of greater salinity than those of the other great oceans. This is because, when water freezes, the salt which it contains in solution crystallises out and falls into the surface layers underneath the ice. Take a small vessel of salt solution and place it in a freezing mixture composed of finely pounded ice, to which has been added one-third of the same quantity of salt. When the first coating of ice forms on the water in the vessel, take it off, and place it in a saucer before a fire until the ice thaws and the water evaporates. No salt will be found to remain behind on the saucer. In other words, the water that evaporates is *fresh* water which, before freezing, held salt in solution. If, however, further ice-coats are allowed to form in the vessel and are removed and evaporated, a slight deposit will be found on the saucer. This is due to the increased density of the water in the vessel. Along the shores of the Arctic, in Siberia, the Samoyedes obtain their supply of salt by breaking the surface coatings of ice which have formed over the frozen marshes, and so collecting the salt which, on crystallising out, has fallen upon the ground.

The Antarctic Ocean.—The Antarctic Ocean surrounds the newly found continent Antarctica. It has only southern shores, and the three great oceans may almost be regarded as mighty gulfs radiating from it. On the continent is to be seen a lofty range of mountains, from which two volcanoes—Mount Erebus and Mount Terror—arise. This land has not always been covered with ice, as has been proved by the existence of coal-deposits. The Antarctic is a much colder ocean than the Arctic, and sends out into warmer seas a larger number of large icebergs than the Arctic Ocean. Some idea of the intense cold which prevails in these regions may be formed from the statement made by Commander Evans in describing the journey of the southern party in the Scott expedition of 1912, when he said that on one occasion 70° of frost were registered. The Antarctic Ocean is much deeper than the Arctic Ocean, but much shallower than either the Pacific or the Atlantic.

Colour of Sea-water.—The colour of nearly all seas is blue, due partly to the reflection of the sky in the waters, partly to the depth of the water, and partly to its salinity. Where the sea is comparatively shallow, the blue is of a greenish tint. The Mediterranean Sea is remarkable for the deep bluish hue of its waters; the Red Sea possibly receives its name because of the minute forms of vegetation, called *algæ*, which exist in its waters, and the Yellow Sea is so named because of the *loess* or sediment brought down by its rivers (see p. 180). The surface water in different parts of the ocean may be frequently observed to sparkle with a phosphorescent glow. This is due to the existence of millions of microscopic animals—the glow-worms of the sea—which send forth a light similar to the light of the firefly. Sometimes they remain on the surface water in a quiescent state, and their presence can only be detected when they glow. Their chief centres of activity are located in the warmer parts of the oceans, and as a ship makes its way through the sea in these parts it leaves in its wake what appears to be a long line of fire of remarkable brilliancy. The Gulf of Mexico and the Caribbean Sea are two very important centres of phosphorescent activity, but the phenomenon is often observable in the North Sea, though not in perfection of brilliancy.

EXERCISES

1. Describe the distribution of (*a*) land and water, (*b*) mountains and plains, as they might be seen from a point far above the North Pole. (Oxf. and Camb. Lower Cert.)
2. Compare the distribution of land and sea in the northern and in the southern hemispheres. State some of the consequences of these facts. (Oxf. Sen. Loc.)

CHAPTER XVIII

Waves and Tides

Movements of Sea-water.—There are three distinct kinds of movement in the waters of the sea. First there are waves caused by the wind, and usually named **wind-waves**, to distinguish them from other waves such as tidal waves. These at the sea-margins do the work of denudation along the coasts. Depending as they do upon winds varying in both force and direction, wind-waves are very irregular and variable. Secondly, there are **tides**, caused by the regular, unvarying, forecastable influences of the sun and moon upon the waters. These tides, by lifting up the waters of the ocean, allow the wind-waves to play over a larger vertical surface of cliff coast. Thirdly, there are **currents** or surface drifts, also regular, easily traceable, and even mappable, actual rivers in the ocean. Currents act as a transporting agent of any detritus that may come in their path. Tidal waves help in the work of both denudation and transport.

Wind-waves.—Take a bowl of water and blow gently upon the water. Notice the little ripples set up. Blow harder and harder, and you will see that the surface disturbance becomes more intensified. This shows that the greater the wind force, the more violent the agitation of the water, and the bigger the waves produced. Tie a good length of clothes-line to a gate-post or other fixture and take the free end of the line nearly as far as its length will allow. Keep this end in your hand and let the rope lie slack upon the ground. Then with a sharp up-and-down movement of the hand propel a series of waves along the line. You will see that the *wave moves forward, but the rope does not.* Watch a field of ripe corn as the breezes blow over it. Although waves are seen to pass right over the field, yet you know quite well that the ears of corn merely bend up and down. In the wind-waves of the sea the same thing happens: *the wave moves forward, but the water does not.* A boat out on the open sea is lifted up by a wave, it drops again when the wave has gone, it is lifted up again by the next wave, and so on. So though wave after wave passes on under the boat, the boat is not carried forward by the water.

The top of a wave is called the **crest**, the depression between two crests the **trough**, the vertical distance from crest to trough the **height**, and the horizontal distance from crest to crest the **length**.

Kinds of Waves.—As you watch the sea from the shore on a calm breezeless day, you are possibly surprised to see the waters heaving and rolling heavily upon the shore. If waves are wind-caused, and no wind is blowing there, how are these slow heavings brought about ? When you throw a stone into a pond the ripples are prolonged far beyond the point of disturbance. So these rollings of the sea under a calm air are the effect of disturbance due to a far-off storm. Such rolling waves are known as **ground-swell.** The lines of more or less parallel waves formed when the ground-swell reaches shallow water on a sloping beach are called **rollers.** When a wave nears the shore its wave-form is destroyed and there is an actual *forward movement* of the water. For as the water becomes shallower the movement of the trough of the wave is checked by friction upon the sea floor, but the crest, receiving no such check, throws itself forward and falls upon the beach with an onward flow. This over-topping of a wave-crest due to the shallower water forms a **breaker.** When the breaker has spent its force up the beach the water commences to return, and it goes on returning *underneath* the next incoming breaker. Thus a seaward undercurrent is formed called the **under-tow.** This under-tow is mostly a surprisingly strong current and is often a source of danger to sea-bathers.

Special waves set up by earthquake disturbances are discussed in the chapter on that subject (see p. 389).

Work of Waves.—In the open sea waves do no more than cause the surface to rise and fall. But on the shores of a country, breakers and rollers do a terrible work of destruction. If you have been to the seaside you will have some notion of the great force with which breakers beat upon the shore ; you will have seen how the sand of the beach is washed backwards and forwards, how the pebbles are rolled about, and how all is accompanied by the scraping, crunching roar of the stones as they rattle and grind together. Examples of the mighty strength of breakers may be seen at many places round our coast, *e.g.* Filey Brigg on the Yorkshire coast, where huge rocks and boulders weighing tons may be seen piled up where the waves have *thrown* them. The force exerted by the blow or fall of a breaker has been measured. In winter the Atlantic breakers on the west coast of Britain often rise to a height of 50 feet, averaging indeed as much as 20 feet, and fall with an average force of a ton to the square foot ; the summer breakers have only about one-third of that strength. The power of these waves is so great that huge blocks are torn from their beds and hurled forward coastwards. On the beaches these blocks are shattered into smaller fragments and finally ground to small pebbles. From both boulders and pebbles, by their rubbing together, particles are worn off so fine that they can float away in the receding water. The pebbles and shingle so formed are then used as the tools by which the waves cut their way into the land; for it is not the direct action of water that undercuts the cliffs, but rather the bombardment of the pebbles and shingle hurled by the waves against the shore.

Tides.—At the seaside one of the most familiar of all phenomena is that the beach is sometimes covered by the sea, and at other times it is a stretch of bare sand. When the beach is covered right up to the promenade you will have heard the remark that it is *high water*; when the waters have receded as far as they will go, you will have heard the remark that it is *low water*. Moreover, you will have noticed that the succession of high water and low water takes place at regular intervals. To you it will have seemed that the water flowed in wave

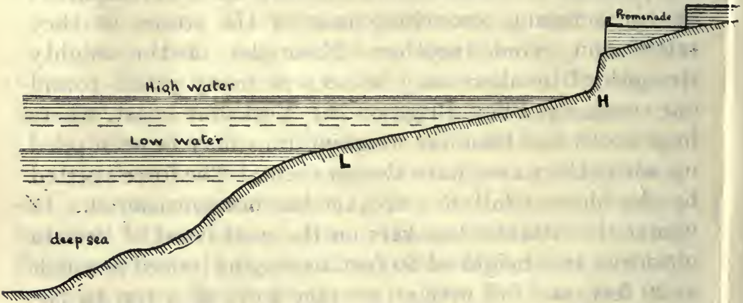

FIG. 67.

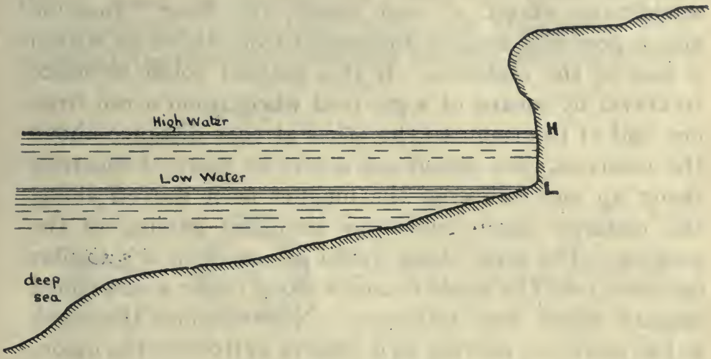

FIG. 68.

by wave to the top of the beach, and then wave by wave flowed out again. And this flowing-in and flowing-out of the water you have called the *tide coming in* and the *tide going out.* Fig. 67 is a diagram of a sloping sea-beach showing the different levels between high water at *H* and low water at *L*. You will see from this diagram that there is a *lifting of the level of the water* rather than a flowing in. The water-level is raised bit by bit, and after each slight rise there is a slightly less subsidence. But as each rise is greater than each succeeding subsidence, the rise in level works up the beach from *L* to *H*. At this point the power that was raising the water-level gradually ceases to act, and subsidence begins to gain on rise, till the waters fall back to their old level at *L*. The difference between the highest high water and the lowest low water is called the **tidal range.** Where no beach is exposed, even at low water, the lifting of the level of the water is more easily perceived, as in fig. 68.

Causes of the Tides.—Imagine a huge steel spring-mattress stretched from one end to the other of your schoolroom about a yard above the floor. Imagine also a powerful magnet suspended from above to within a foot of the mattress. If this magnet could be made to travel by means of a grooved wheel upon a rail from one end of the room to the other at that distance above the mattress, you would see a sort of wave of mattress rising up and following the magnet as it moved along, the mattress again subsiding after the passing of the magnet. The same thing would also happen if a similar mattress could be made to move along under a suspended magnet which was stationary. Now consider the earth as the mattress, moving as it rotates in front of the moon, which acts as the magnet. The whole earth is drawn towards the moon a few feet, leaving the waters of the oceans and seas bulging out on the side of the earth remote from the moon's influence, because they are too far from the moon to suffer any attraction. But not only is the solid earth thus slightly drawn towards the moon; the waters of the oceans and seas on the side of the earth nearer the moon, being more mobile, are also drawn a few feet nearer the moon than the solid earth. In this way are formed on opposite sides of the earth two waves which travel round the earth as it rotates before the moon. These waves are the **tidal waves** that appear along the shores of all seas and oceans twice during each rotation of the earth. Thus you say, " The tide is coming in," when the tidal wave is approaching the shore; and you say, " The tide is going out," when the sea is subsiding after the passing of the tidal wave. The tide is said to be *flowing* as it comes in, and *ebbing* as it goes out. If the earth were rotating and the moon were stationary, there would be a high tide every twelve hours. But the moon is slowly revolving around the earth in the same direction as the earth's rotation once a month.

Hence, since the moon rises about the thirtieth part of twenty-four hours later every day (*i.e.* about fifty minutes), the tides are about fifty minutes later every day.

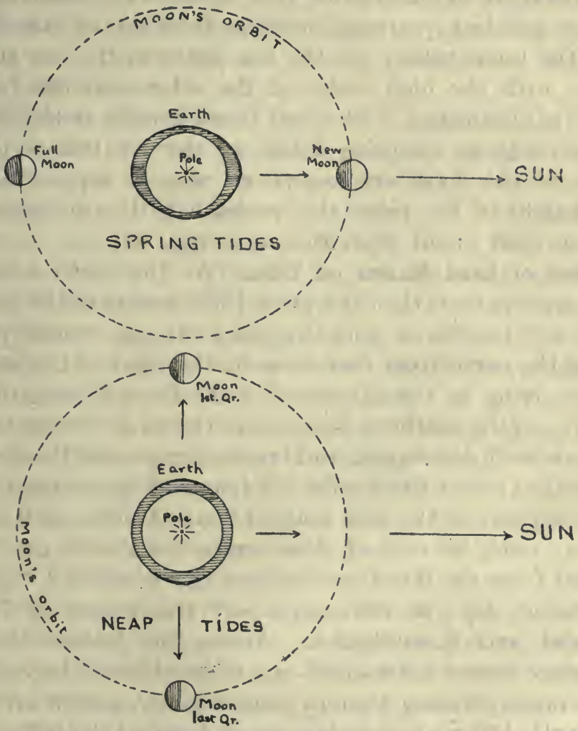

FIG. 69.

Not only the moon, but also the sun has this tide-raising power; but the sun's power is only two-fifths that of the moon. When the sun and moon are in conjunction or opposition, that is, at new moon and at full moon, the solar tides and the lunar tides coincide. At these times the high tide is the highest possible and the low tide is the lowest possible (**spring tides**). When the sun and moon are in quadrature, that is, when the moon is in its first and last quarters, the solar tides do not coincide with the lunar tides ; for the low water of the one then agrees with the high water of the other and the total effect is diminished. At these times neither is the high tide so high as at spring tides, nor the low tide so low. Tides of this kind are known as **neap** or nipped **tides.** The height of the tides also varies with the distance of the sun and moon from the earth (fig. 69).

Effect of Land Masses on Tides.—As the earth rotates from west to east, the tidal wave, if the waters of the earth were not interfered with by land masses, would pass round the earth from east to west, the crest of the wave always lying in the direction of the lines of longitude. As it is, in the southern hemisphere the west-moving tidal wave is well developed, and travels across the Pacific at the rate of about 1,000 miles per hour. Suppose the tidal wave appears off the west coast of South America at 9 a.m. on any date, its rate of flow across the Pacific may be judged from the fact that in about ten hours (*i.e.* 7 p.m. the same day) it will arrive off the coasts of New Zealand and Kamtchatka. Across the Indian Ocean the wave moves from south-east to north-west, travelling more rapidly in deep than in shallow water, until it arrives off South Africa at sometime about noon on the following day. On entering the Atlantic, however, the wave swings round the Cape of Good Hope and passes up this ocean as a north-moving wave at the rate of about 700 miles an hour. Then, advancing more rapidly in mid-ocean than on the margins, it swings round again after passing the equator, and reaches the British Isles at about

4 a.m. on the next day, actually moving from the south-west towards the north-east. In the Pacific its tendency is generally westwards. When the tidal wave reaches the shallow water near the shores of any country, its form and velocity become greatly modified by friction, and **tidal streams** are set up.

Tide-races and Bores.—In narrow channels between two islands or between islands and the mainland these tidal streams acquire great speed, and are then known as **races,** *e.g.* the Race of Alderney in the Channel Islands, and the tidal race in the Pentland Firth in the north of Scotland. The meeting of two tidal waves in a confined passage will often give rise to a **whirlpool,** as also will a race when it rushes upon a line of sunken rocks, or even upon the "groynes" which are commonly built along the eastern English coast to protect the beaches and prevent the excessive drifting of sand or shingle. There is a famous whirlpool called Corrievrekin (the cauldron of Brecan) off the west coast of Argyllshire. It is caused by the meeting of tides (running thirteen miles an hour) from the north and west in a narrow passage between two small islands in the sound of Jura. The tidal race rushes upon a pyramid-shaped rock, which rises with a rapid slope from a depth of 100 fathoms to within 15 feet of the surface. Another famous whirlpool is the Maelström (the "grinding" stream), near the west coast of Norway, between two islands of the Lofoden group. If a tidal wave flows into a shallow narrowing inlet like the estuary of a river, it gathers height as it advances between the converging banks. Such a high tidal wave advancing up any narrowing gulf is known as a **bore.** In the case of an estuary, the energy of the bore is gradually decreased by the downflow of the river. The most celebrated bores are those of the Ganges, the Indus, and the Brahmaputra. In the Hûgli branch of the Ganges the bore travels 70 miles in 4 hours as a wall of water 7 feet high. In the Bay of Fundy the bore occurs on a very gigantic scale; for between low and high water there is a difference as great as 70 feet. Steamers at some of the villages on this bay lie stranded on the sand with steam up ready to start the moment the tide catches them. Many English estuaries have bores, *e.g.* the Solway Firth, the Severn, and the Trent. At Chepstow, on the Wye, occurs the highest tide in the British Isles. The Severn bore as it passes the mouth of the Wye is sometimes as much as 40 feet above mean sea-level. The bore of the Trent is called the Ægir.* A sea with a narrow entrance blocks out the full force of the tidal wave, and this is the reason why seas like the Mediterranean and the Baltic are very little subject to tidal rise and fall.

Co-tidal Lines.—Generally speaking, in the northern hemisphere, the moon is due south of every place on any meridian as, by the rotation of the earth, that meridian passes under the moon. In theory, the time of high water at any place should agree with the time when the moon is due south of (*i.e.* southing at) that place. But, after the southing of the moon, there is always an interval of delay in the arrival of the tidal wave. The causes of the delay are the unequal depths of the sea at different places, the irregular shape of the land masses, the varying widths and lengths of the channels through which the tidal wave may pass, the action of the wind, and so on. Not only do these things cause delay at all places, but they also cause the amount of delay to vary from place to place—or from port to port, since it is naturally at seaports that most tidal observations are made. The interval for any port between the southing of the moon and the next high tide is called the **establishment of the port.** When the moon is in its first and third quarters (*i.e.* to the east of the sun) and the solar tide is on the west, a port will have high water earlier than if the tide were caused solely by the moon's attraction. This variation is known as the *priming* of the tide. But when the moon is in its second and fourth quarters, the solar tide lags behind the lunar tide, and high water at any port is later than otherwise would be the case. This retardation of the tidal wave is known as the *lagging* of the tide. As soon as the establishments are determined for a sufficient number of ports, lines can be drawn on a map connecting all those ports that have their high water at the same moment of time. These lines are called **co-tidal lines,** and the map a **co-tidal map** (fig. 70). From such a map may be seen the advance of the tidal wave through the sea, and its rate of progress from one port to another. On a map of the world the lines from port to port across an ocean or sea are purely conjectural, since observations of high and low water are impossible in mid-ocean. A fair degree of accuracy, however, is possible in the case of the British Isles. In passing up a channel or estuary the tidal wave often becomes bent into a sharp curve. In such a case the point of the curve is the highest part of the tidal wave.

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* From *Aegir*, the name of an old Norse sea-god.

The Tides of the British Isles.—The tidal wave that reaches the British Isles comes from the south-west and divides into three branches (fig. 70). One moves up the English Channel, another moves up the Irish Sea, the third passes up the west shores of Ireland and Scotland, round the North of Scotland, and down the North Sea, meeting, twelve hours late, the first branch of the next tidal wave off the mouth of the Thames. The English Channel branch passes round the Isle of Wight in two branches, one to Southampton via the Solent, the other via the Spithead three hours later, thus giving South-

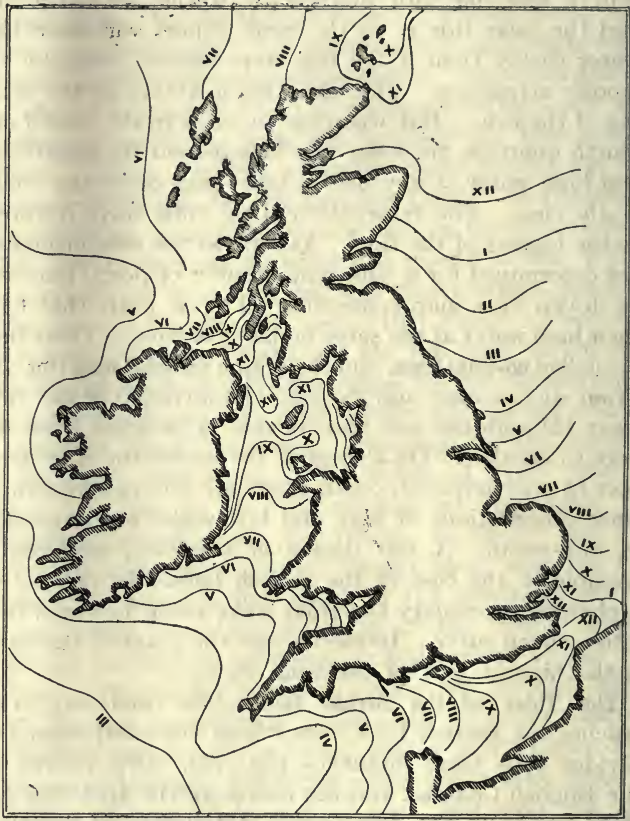

Fig. 70.

ampton the enormous commercial advantage of four high tides every twenty-four hours instead of the normal two.

At Havre two high tides appear together, with the result that high tide at that port lasts much longer than usual, a phenomenon that is of considerable advantage to Havre's Atlantic traffic. Double tides also occur at Poole and at Weymouth. The co-tidal line marked IV o'clock off south-west Land's End represents the same wave that left the Cape of Good Hope fifteen hours previously (see a co-tidal map of the world).

Seiches.—A mobile substance like water must be affected more or less by the variations in pressure of the atmosphere above it. Where air-pressure is high, the surface of a sea or lake will be depressed; where the air-pressure is low, the water surface will stand higher than usual. This alternation of high and low water corresponding to low and high air-pressure is called a **seiche.*** The name was given to this phenomenon by Professor Forel, who by his observations on Lake Geneva in 1869 laid the foundations of our present knowledge of the laws of seiches. This particular kind of rise and fall probably takes place on the surface of all bodies of water; but it can be observed with ease and accuracy only on comparatively small bodies such as lakes and inland seas. The seiche is not a simultaneous rise and fall of the whole of a lake surface, but a fall of one or more portions of the surface with a corresponding rise of the others, followed by the rise and fall of those portions. Take an ordinary pudding-basin and fill it three-quarters full of water; stand it on a table, tilt it slightly sideways, and then jerk it back to its position of rest upon the table. If you watch the surface of the water, you will see it oscillate from side to side of the basin, with alternate rises and falls at the opposite margins, but with practically no difference of level in the middle. This exactly illustrates the simplest form of the seiche in which depression of the surface occurs in only one place at a time. The more complicated forms occur when there are two or more regions of depression at the same time. In Lake Geneva the rise of the seiche sometimes reaches 6 feet. Small seiches are known to occur on Lochs Katrine, Ness, Earn, and other Scotch lakes. At Chicago on Lake Michigan and at Duluth on Lake Superior there is also a range of a few inches.

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* Winds and earth tremors are also credited with producing seiches.

Tidal Utility.—The rise and fall of the tides is a force so constant and powerful that it seems a pity man does not make more use of it. Small uses are already found for this great force, but a common and extensive use of it is yet to come. At some seaside towns in England, *e.g.* at Filey, bathing-places are so built that sea-water can enter at each high tide and be emptied out again at each low tide. On the New England and Nova Scotian coasts similar structures have been built, and after they have been filled automatically at high tide, the water is allowed to escape through sluice-gates at low tide in such a way that it turns a wheel geared to a corn-mill. Land-warping * is done by tidal gates at many places on the east coast of England. At Ferriby Sluice in Lincolnshire the muddy, coffee-coloured tidal waters are allowed to cover the land within the required area at high tide, and before this water is released at a subsequent low tide, a deposit of fine mud has been laid down. Just near by, on Read's Island, the tidal waters are doing a similar work quite of their own accord. Thirty years ago this was a very small island with a plot of grass in the centre on which a few cattle were reared. Now the island is hundreds of acres in extent and has an enormous number of cattle grazing upon it. Spurn Point also owes its existence to material which, after being carried down the Yorkshire coast by the tides, sinks on meeting the waters of the Humber. The ebb and flow of the tide (strengthened sometimes at ebb by the outflow of a river) preserve open passages through sandbanks when they fringe a coast. Thus the important harbours of Charleston and Savannah in the U.S.A. would be quite sandblocked and useless, were it not for the strong tidal currents which keep open channels deep enough for sea-going vessels. Tides are further beneficial in maintaining a circulation in bays, and especially in harbours, where the water might otherwise become stagnant and possibly offensive. The tide is the scavenger of all British harbours in this way. The reverse, however, is the case in the Mediterranean, where tide-influence is slight. There the harbours are not scoured twice each day (or oftener) by the strong tide, and the result is that some of them, by reason of the sewage and other unpleasant matter that is poured into them, are not only indescribably offensive, but also a frequent source of fever. The harbour of Bari in South-east Italy, which is little more than a stagnant cesspool, is notoriously unhealthy for this reason.

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* This name is given to the enclosing of a body or sheet of water till the sediment it holds in suspension has been deposited. The operation can only be carried out on flat, low-lying tracts which can be readily submerged. The result is the same as that effected by the inundation of the Nile: the land is covered with a top-dressing of natural manure.

When a river has a very flat flood-plain, the tidal wave will flood the land every time it flows up the river. Previous to the seventeenth century the flooding of the Fens was caused by the backing of the tide up the Great Ouse. The flood-plain of this river is so flat that

Cambridge, 50 miles from the sea, is only 25 feet above sea-level, and with such a slight fall it was quite easy for the tide to back up as far as Earith twice a day. To prevent this flooding of the Fens a drain 40 feet wide was cut from Denver to Earith, to receive the tidal backwash. The drain, named after the nobleman who undertook the work, was called the Bedford Level. It relieved the flooding of the Fens, but did not succeed in draining them properly. In 1650 another drain was cut parallel with the first, and named the New Bedford Level, although the work had originally been planned by his Majesty Charles I. The New Bedford Level was 100 feet wide, and a sluice was built across the Great Ouse at Denver to turn the incoming tide up the New Drain, leaving nothing but normal water between Denver and Earith. The New Bedford Level is now the main bed of the Ouse, and the old bed from Earith to Denver is known as the Old West River (which is a mere ditch till the Cam enters it).

Exercises

1. On the east coast of England rock material is continually falling from the cliffs. What becomes of this ?
2. What are the conditions necessary for the formation of a tidal bore ? Quote examples.
3. " The tide-raising power of the moon is not the absolute attraction on the earth as a whole, but its differential attraction." Explain this.
4. Give some account of the movements due to the tides around the shores of Great Britain. (Oxf. and Camb. Sch. Cert.)

5. Give an account of the movement of the tide in the Atlantic Ocean, calling attention to any places where its rise and fall is unusually great or where its direction of movement is abnormal. (Oxf. and Camb. Lower Cert.)

6. The tidal wave in the Southern Ocean moves from east to west, in the Indian Ocean it moves from south to north; it approaches the west and south shores of the British Isles, speaking generally from the west, and on the east coast of the British Isles it travels from north to south. Account for these changes in direction, and mention any result of the various directions of the tides round the British Isles.

7. Describe the Maelström, and explain how eddies and whirlpools are caused.

8. What are co-tidal lines? What is proved by the form of these lines as to the heights of tides? Name some places which have high tides and some which are nearly tideless. Why is there no tide in the Mediterranean Sea? (Civil Service.)

9. Spring tides at Liverpool rise to a height of about 26 feet, at Bristol to 33 feet, at Greenock to 10 feet, and at Dublin to 14 feet. When high tide occurs at noon at Dublin, there is high tide at Liverpool at 12.22 p.m., at Bristol at 8.30 p.m., and at Greenock at 1.18 p.m. Explain why the times and the heights of the tides at these places are so different. (Civil Service.)

10. What changes would be observed in the hour and the height of high tide, if the observations were continued at a place for one month? State briefly the cause of each difference that would be noticed. (Northern Univ. Matric.)

11. Upon what principles does the formation of the tides depend? Describe the differences between tidal phenomena (*a*) in the open ocean, (*b*) in shallow seas, (*c*) in estuaries. (Oxf. Sen. Loc.)
12. Explain the course of the tidal wave around the British Isles. Explain any peculiarities in the tides of different parts of the British coasts. (Lond. Univ. Matric.)
13. What geographical considerations have favoured the recent marked increase in the importance of Southampton as a port of call for Atlantic liners? (Oxf. and Camb. Sch. Cert.)
14. The hours of high and low water at a seaport, and the difference of level between them, vary from day to day.

    Give a general account of the changes which take place. Can you connect the changes with the phases of the moon?

    Explain why there is a difference in the rise and fall of the tides on the same day in the Bristol Channel and the Gulf of Genoa. (Oxf. Sen. Loc.)
15. Give a short account of the chief phenomena of the tides, describing the principal movements of oceanic waters which are due to tidal influence. Under what conditions do *tidal currents* occur? Give and explain instances in which tidal movements are (*a*) favourable, and (*b*) unfavourable, to navigation. (Oxf. Sen. Loc.)
16. What is meant by high tide, low tide, and foreshore? Why do the height of the tide and the extent of the foreshore vary at different places? (Camb. Jun. Loc.)
17. What commercial advantages are to be gained from

a tidal river? Give the approximate tidal range at London, Bristol, Plymouth, Liverpool, and Chepstow respectively? Explain the statement, "The mean establishment of the port of Bristol is 7 hrs. 13 min."

18. How are the tides produced? What is the difference between spring tides and neap tides, and how is this difference caused? (Civil Service.)

CHAPTER XIX

Ocean Currents

Definition and Cause.—There are perceptible movements of the water from one part to another in all the large oceans. These movements take the form of streams or rivers in the ocean, flow at the rate of nearly four miles per hour, and are called currents. Their direction is always constant, and their circulation is closely associated with the cyclonic circulation of the atmosphere. In the attempt to ascertain the causes of these currents much has been attributed to the effects of the prevailing winds, the configuration of the coast and its submarine approaches, the differences in temperature and density of the sea, and indirectly the earth's rotation. All of these assist in the formation of currents, but it is now generally accepted, from the close resemblance which the atmospheric circulation bears to the oceanic circulation, that the prevailing winds constitute the most powerful agent in the production of these movements.

Prevailing Winds and Currents.—Within a belt round the globe, bounded by the parallels 30° N. and 30° S. latitude, the prevailing winds, known as the north-east and south-east trades, blow towards the equator. North of this belt blow the south-west anti-trades, and south of it the north-west anti-trades (see p. 160). Between 40° S. and 60° S. latitude the variable and strong west winds, which have a great effect on the waters of the Southern Ocean, blow all the year round. The result of a system of winds like the last on a large expanse of water may be shown by performing a simple experiment, which will go a long way to explain the causation and

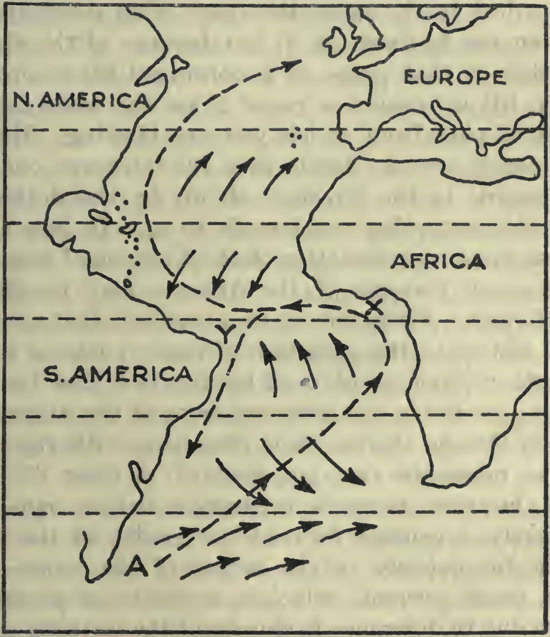

Fig. 71.

circulation of the main ocean currents: On a square tray, model in clay a rough outline of the land bordering the Atlantic Ocean as shown in the diagram fig. 71. Let the clay be about an inch deep throughout. Fill up the hollow intervening between the two patches of clay with water till it reaches nearly to the level of the clay. Sprinkle on the surface of the water a small quantity of bran or sawdust, and blow with a tube at *A* in the direction of *X*. Immediately there will be seen to take place a movement of the surface water towards *X*, its movement being shown by a corresponding motion of the bran or sawdust in the same direction. This circulation will be seen not to finish at *X*, but because of the shape of the clay at that place, it is continued back across the water till it reaches a point *Y* on the same side, but north of that from which you are blowing. Here the sawdust is seen to divide into two streams, one going northwards in the direction shown by the dotted line, the other returning southwards to *A*. In fact a more or less exact representation of the direction of flow of the chief ocean currents of the Atlantic may be obtained in this way. From this we may conclude that one of the chief factors in the causation of ocean currents is wind. A further proof is adduced by the fact that the great ocean currents in the monsoon areas of the Atlantic and Pacific Oceans change their directions with the change of the monsoons (see pp. 154–6). A clear distinction must, however, be made between a surface *drift*—which is merely a general forward movement of the surface water due entirely to the action of the wind—and a great ocean current—which is a stream of considerable depth due to difference in density of the water in addition to the action of the system of prevailing winds. For example, it would be entirely wrong to speak of the Gulf Stream, after it has passed the parallel 40° N. latitude, as an ocean current, because its direction and very existence depend upon the south-west anti-trade winds and upon nothing else. Its correct name, then, is the **Gulf Stream Drift**, or better, the **North Atlantic Drift.**

Ocean Currents and the Shape of the Land.—The flow of the great ocean currents depends mainly on the direction in which the winds blow them, and on the shape of the large land masses that obstruct their path and deflect them. In accordance with Ferrel's Law (see p. 149), the prevailing winds are deflected " clockwise " in the northern hemisphere and " counter-clockwise " in the southern. The currents are indirectly deflected in this sense, since they are driven by winds that have themselves suffered deflection from the earth's rotation; but they are also directly deflected in accordance with the law (see p. 149). A much more important matter is the deflection caused by the land masses. Many of the great ocean currents and drift streams are prevented from continuing their flow in their original course through the opposition of a land mass that acts as an insuperable barrier and thus deflects them. The North Equatorial current in the Atlantic is so affected by the American continent which bars its course on entering the Gulf of Mexico through the Strait of Yucatan. Consequently, it is deflected northwards, and on leaving the Gulf of Florida it becomes the Gulf Stream. To secure an ideal circulation of ocean currents, our globe would need to be a perfect hydrosphere. If such a condition were possible, there would be set up two east-to-west currents encircling the hydrosphere—one flowing a little to the north of the equator, the other slightly to the south of it. These theoretical currents would follow the theoretical winds that would blow if there were no deflecting land masses.

Temperature of the Sea and Currents.—In all oceans there are what is known as convection currents (see p. 17), which involve a movement of the deep cool waters of the temperate zones towards the equator. These in their turn cause a surface movement of the water to be set up in the opposite direction, *i.e.* from the tropics towards the poles. The underneath flow of this circulation, called the "polar creep," is strengthened by the need there is to supply the deficiency lost in the tropics through evaporation. That there is a sinking of cooler waters as they flow equatorwards and a flowing over them of warmer waters from the equator polewards is proved by the fact that the sea-bottom is inhabited. Without a fresh supply of oxygen there could be no life near the ocean bed. The sinking of the water flowing equatorwards begins at about the parallels 40° N. and 40° S. latitude. This sinking is due to the fact that the flow is entering a region of warmer and therefore of less dense water. This circulation is now called *not* a convection current, but the **planetary circulation.** It differs from the ocean currents in that its circulation is *vertical.* Ocean currents are a **horizontal circulation**, although the constant winds that cause the ocean currents are the planetary circulation of the atmosphere (see p. 158). These vertical movements in the oceans are very feeble compared with the effect of winds, for below 1,000 fathoms the difference in temperature between the waters at the tropics and those at the poles is almost negligible. We can show this clearly by comparing the ocean floor in those parts, in which a strong deep current prevails, with the ocean bed in other places. Along the Wyville-Thomson Ridge in the Arctic Ocean, across which a strong current flows from the poles, scarcely a single particle of sediment is to be found. If the currents set up by thermal differences were strong, the plateaux and ridges of other parts of the ocean bed would be swept clear of marine deposits of all kinds. That this is not so proves that the circulation is a very gentle one, and that thermal differences merely aid in a slight measure the oceanic circulation. Differences of temperature in the oceans, however, give rise to dense fogs and frequently to sudden and terrific storms. Warm currents raise the temperature of the air which is in contact with the ocean, while cool currents lower it. The result is to cause great differences in atmospheric temperature over small and large areas, and thus create cyclonic disturbances of more or less intensity (see p. 173). High temperatures cause much evaporation, but in the great oceans their effect in this respect is small. In enclosed seas, however, they provide us with one of the chief causes of currents.

The Earth's Rotation and Currents.—In accordance with Ferrel's Law (p. 149), all moving bodies on the earth's surface suffer deflection or deviation from their course, because of the earth's rotation. This is as true for currents as for winds. All water particles, when set in motion by the prevailing winds, undergo a deviation from a straight path towards the right as they move in the northern hemisphere and towards the left in the southern. If we examine a map of the currents of the Atlantic Ocean, we shall find that the North Equatorial Current on nearing the West Indies sweeps northwards along the coast of America, while the South Equatorial Current on nearing the Brazilian coast sweeps southwards. The degree of deviation is about 45° to the right of the direction of the wind in the northern hemisphere and to the left in the southern. It is clearly apparent that the effect of the earth's rotation is to cause all the moving particles of water to lag behind. In the tropics, where the rate of rotation is at a maximum, there the lagging is greatest. This tendency of the water to keep back, while the earth is going on, enables the prevailing winds to form the equatorial currents which flow westwards. Again, the deeper layers lag behind the upper in deflection, and the velocity of the current rapidly diminishes in consequence.* The Gulf Stream Drift, while on its way northwards from the coast of Florida to the banks of Newfoundland, decreases from a velocity of about five miles an hour to one mile and a half per hour. The same thing is true of the Brazilian current in the southern hemisphere: its velocity decreases as it moves southwards, and it becomes more and more deflected towards the left. The same remarks apply to the chief currents in the other oceans.

Currents of the Atlantic.—South of South America in the Southern Ocean the west wind causes a drift stream to be set up that traverses the South Atlantic in an easterly direction (fig. 72). On reaching the shores of South Africa it becomes merged in an Antarctic drift forming the Benguela Current, which, being deflected by the land, flows northwards. The Benguela Current, like most currents, takes its name from the country by which it flows. As it goes north it comes under the influence of the south-east trades, which in time cause it to flow farther away from the African coast, till in its turn it becomes the South Equatorial Current. This current is driven north-westwards by the same winds and continues to flow almost parallel to a similar current called the North Equatorial Current. The flow of both across the ocean is affected not only by the earth's rotation, but also by the direction of the winds which are being slightly deflected to the right in the northern hemisphere and to the left in the southern—that is, assuming you are looking in the direction in which the wind is blowing. The northern current is, therefore, being deflected towards the north-west; while the southern current is turned slightly towards the south-west. Off the West Indies the North Equatorial Current is split up into two parts by the Greater Antilles. One part enters and circles the Gulf of Mexico, leaving it through the Straits of Florida; the other part flows along the east coast of the islands and joins its northern half where the latter makes its exit from the Gulf. Thence this current

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* This lagging of the waters sets up a friction which is the main cause of the diminution of the rate of the earth's rotation.

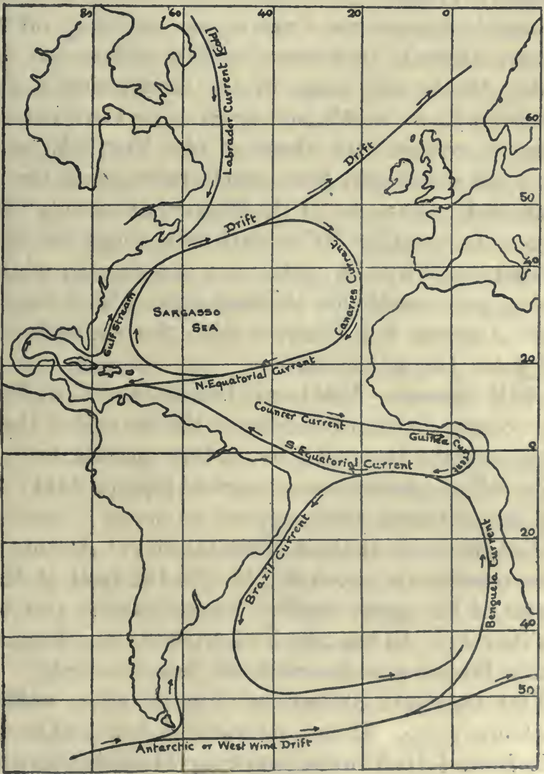

FIG. 72.

flows northwards along the east coast of America till, on reaching Cape Hatteras, it is no longer called a current but the Gulf Stream Drift.

Between the North and South Equatorial Currents there is a counter-equatorial current flowing eastwards, due to the heaping-up of the water in the Gulf of Mexico. This current on reaching the Guinea coast of Africa becomes the Guinea Current.

The South Equatorial Current on arriving off Cape St. Roque (Brazil) undergoes a bifurcation—an effect, no doubt, due to the shape of the land which it meets. One division flows north and enters the Caribbean Sea, mingling its waters with those of the North Equatorial Current; the other part goes south, flowing off the coast of Brazil under the name of the Brazilian Current. When it reaches the parallel 30° S. latitude, a portion of it is driven eastwards by the north-west anti-trades, while the remaining part continues to flow along the lower coast of South America till it meets with the Antarctic Drift flowing from the polar seas.

The Gulf Stream.—North of Florida the Gulf Stream may be easily distinguished from the water of the surrounding ocean. At night its waters sparkle brilliantly and give off a phosphorescent glow (see p. 251); while during the daytime they appear to have a very deep bluish tint, because of their great salinity. At this point their temperature is about 80° F. In the Gulf of Mexico the water of the ocean suffers concentration, and so increases its rate. In the Strait of Yucatan the Equatorial Current is 90 miles wide and 1,000 fathoms deep, but at Key West the Gulf Stream is only 50 miles wide and 350 fathoms deep. Hence its rate of flow at the latter place is from 4 to 5 miles per hour—that is, nearly five times faster than the Equatorial Current enters the Gulf of Mexico. As the Gulf Stream flows northwards it expands, slackens its speed, and gradually loses its very high temperature. When off Cape Hatteras the influence of the anti-trade winds makes itself felt, and its course is then across the North Atlantic. It makes its way east as a *drift*, and a drift only; and on reaching the west coast of Europe the drift bifurcates. One part now flows southwards towards the Canaries and Cape Verde Islands; the other portion reaches the west coast of the British Isles. After drifting past the western shores of our islands, this portion divides; one division flows along the coast of Norway, the other bends round and washes the south coast of Iceland. At latitude 45° N., where the main drift bifurcates, commences the North Atlantic Swirl formed by the Drift Stream, the Canaries Current, and the North Equatorial Current. Within this circle lies a very large area of the ocean, covered with sea-weed, wreckage, and marine matter, on which a large number of peculiar animals live. This part of the ocean is called the **Sargasso Sea.** It will be noticed, on referring to a map of ocean currents, that there is a swirl or vortex of this kind in each of the oceans. The influence of the Gulf Stream and of the Gulf Stream Drift on the climate of those countries it washes is of immense importance. The equable climate enjoyed in our islands is due to the high average temperature of the sea that surrounds us and to the fact that we receive an on-shore wind (see p. 310) that always brings warmth. The effect of the Gulf Stream Drift on the climate of the British Isles may well be seen on comparison with that of another country like Labrador which is situated within the same degrees of latitude.

Arctic Currents.—From the Arctic Ocean a well-marked current of very cold water sets downwards along the west coast of Greenland. This current carries huge masses of ice along with it and joins a very powerful current which flows down through Davis Strait known as the **Labrador Current.** When off the coast of Newfoundland, this stream of very cold water meets with the Gulf Stream Drift. The result is to melt the icebergs that have been carried down from the polar seas ; and these deposit their load in the ocean bed. In this way constant additions are always being made to the famous fishing Banks of Newfoundland, and it is possible that the whole of the Banks owe their origin to the same cause. This part of the Atlantic is very dangerous to navigate because of the prevalence of dense fogs, caused by the condensation of the moisture held by the warm atmosphere above the Gulf Stream Drift when it comes in contact with the cool layers that are above the cold Labrador current (see p. 192). From Newfoundland part of this cold current makes its way south, flowing between the Gulf Stream and the American coast. Near Cape Hatteras it is no longer discernible, and its waters gradually sink because of their greater density. The name given to this part of the current is the **Cold Wall,** since it exerts a cooling influence on the east coast of America.

Currents of the Pacific.*—Little difficulty can be experienced in understanding the circulation of the currents of this ocean, if those of the Atlantic have been grasped. South of the South Island of New Zealand, there may be seen an easterly drift flowing across the ocean driven by the " brave west winds." This drift, on reaching the west coast of South America, is reinforced by an Antarctic drift, flows north along that coast, and together they assist in forming the **Peruvian Current.** As is the case with the Benguela Current in the Atlantic, so the Peruvian Current, acted on by the south-east trades, becomes the South Equatorial Current, which flows across the ocean in a line almost parallel to that of the North Equatorial Current. When some distance off the Australian continent this stream bifurcates. One part flows north to join the North Equatorial Current off the Philippines, and of this a small portion enters the Indian Ocean through Torres Strait. The other part flows along the east coast of New South Wales and mingles with the Antarctic Drift off the coast of New Zealand. The North Equatorial Current, on reaching the Philippines, is deflected northwards along the east coast of the Japanese Islands until it reaches the area of the anti-trade winds. Thence it is driven across the northern Pacific as a drift under the name of the **Kuro-siwo** or **Black Stream** of Japan. Its course on reaching the south coast of Alaska is determined by the shape of the American continent. Flowing south, it entirely disappears in the warmer waters of the tropics. Its effect on the climates of the east coast of Japan and the west coast of British Columbia is similar to that of the Gulf Stream Drift on the British Isles. This drift stream confers a great benefit on the inhabitants of the Aleutian Islands by carrying driftwood to them from the Chinese rivers. These islands are treeless, and the wood thus supplied is used by the islanders for the building of their boats and houses and the making of furniture, etc. Again there is a cold current flowing down through Bering Strait and making its way south between the Kuro-siwo and the Asiatic coast. This cold current is similar in every respect to the "Cold Wall" that washes the east coast of North America. The Californian Current

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* In reading this chapter a map of the ocean currents should be constantly consulted (*vide* Meiklejohn's Comparative Atlas, Plate 5).

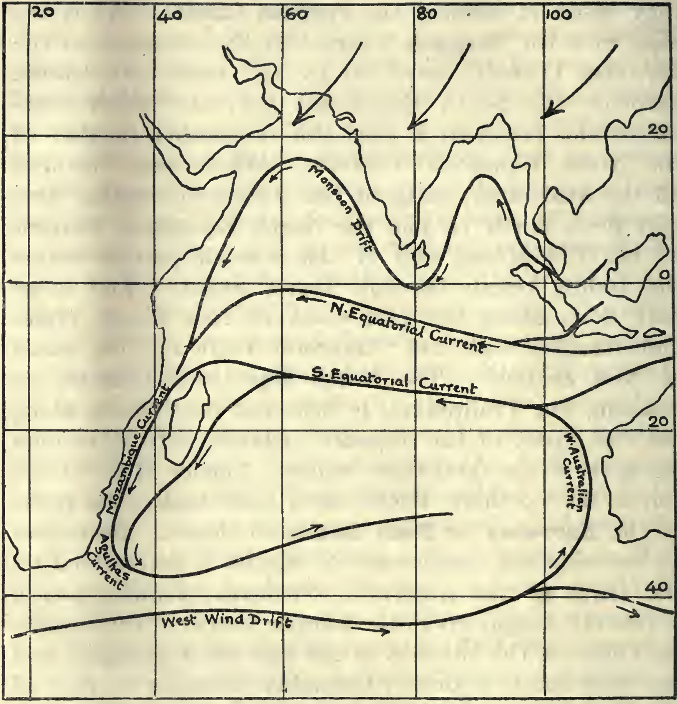

FIG. 73.

flowing south from the Kuro-siwo Drift completes the circular whirl of the North Pacific.

Currents of the Indian Ocean.—As in the other oceans, the westerly wind of the Southern Ocean forms a drift that traverses the southern part of the Indian Ocean in an easterly direction. This drift, on arriving off the south coast of West Australia, is strengthened by a flow of cold water from the Antarctic, and the two on uniting flow northwards and form the West Australian Current (fig. 73).

In its turn this current, on being reinforced by a supply of water that enters from the Pacific between Java and Australia, assists in causing the South Equatorial to be formed. The course of this stream is now south-west, flowing across the ocean, till on reaching the north coast of Madagascar it bifurcates, one part flowing through the Mozambique Channel, while the other portion rejoins it near the Natal coast under the name of the Agulhas Current, so called because the Agulhas Bank deflects the current to

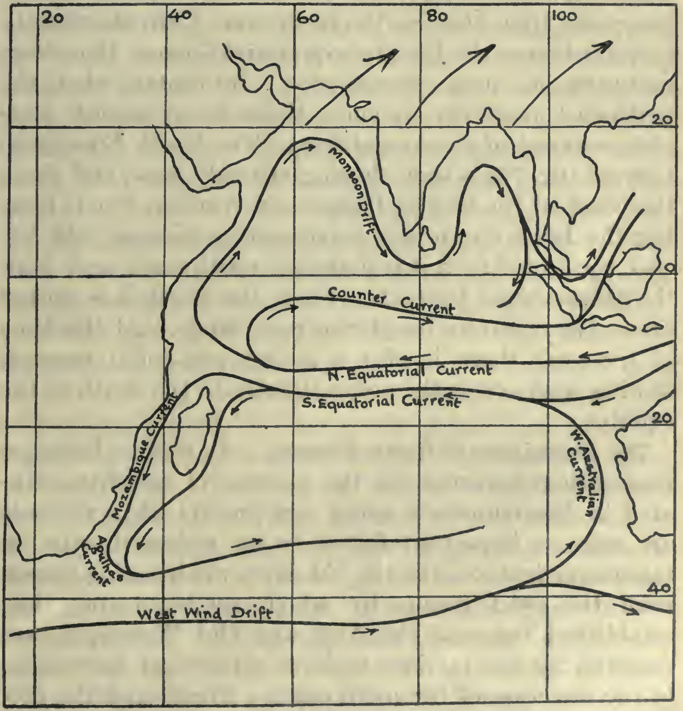

FIG. 74.

the east, thus preventing it from continuing to flow in its south-westerly direction. The currents of the northern part of the Indian Ocean are not so clearly marked nor is their circulation quite the same as those of the other oceans. This is due to the effect of the Monsoons. The North Equatorial Current is at times almost indiscernible. In summer, when the south-west monsoon is blowing, there is set up a South-west Monsoon Drift (fig. 74) that eddies round the Arabian Sea and the Bay of Bengal, and afterwards enters into the Pacific circulation. At the same time the North Equatorial Current scarcely exists, whereas the Counter-equatorial Current that flows eastwards is much strengthened. In winter, when the north-east monsoon prevails, there is an almost complete reversal of these conditions. The North Equatorial Current (fig. 73) is then flowing strongly west, and along the coast of the Bay of Bengal and Arabian Sea is flowing the Drift due to the north-east monsoons. Off the east coast of Africa it is deflected southwards and joins the Mozambique Current. From this point it is wafted across the ocean by the strong west winds. At this time of the year there is also a strong equatorial current, flowing west across the ocean slightly to the south of the equator.

The Importance of Ocean Currents.—As well as having a moderating influence on the climate of countries situated in the temperate zones (see pp. 214–215), currents are also an important factor to be reckoned with by marine navigators. In the old days, when sailing vessels were the chief means by which communication was established between the New and Old Worlds, it was essential for the mariner to have a thorough knowledge of the direction of the main ocean currents and the prevailing winds. As has been shown, there is a very marked similarity in the movements of both, so that a mariner, who neglected to take them into consideration and attempted to sail his vessel in the face of them, would soon recognise the impossibility of his task. If we examine any map of the chief ocean currents, and compare it with a map illustrating the direction of the prevailing winds, we shall understand the reason why sailing vessels bound to Australia usually choose as their outward journey the course round the Cape of Good Hope, and as their return journey the route round Cape Horn. By doing so, full advantage can be taken of the assistance which the winds and currents give on the voyage. Starting from the British Isles, at first the vessel would receive little aid from either currents or winds. But on reaching about the fortieth parallel north latitude, she would enter the region of the Canaries Current, and soon the north-east trade winds would lend her force to cross the Equatorial Current and reach the equator in mid-Atlantic. Several days might now elapse before she was able to make any headway out of this region of calms, generally spoken of as the Doldrums (see p. 159). On receiving a favourable breeze, her route would next be directed by the Brazilian Current, which in due course would send her across the Atlantic, assisted by the strong west winds until she finally reached the Cape of Good Hope. Her easterly course towards Australia would be still maintained, so long as she remained in the same latitude, and her rate of progress would be increased because of receiving further assistance from the South Antarctic Drift, which also flows in the same direction. On leaving Australia, the " brave west winds " of the Pacific would waft her across to Cape Horn and well on into the Atlantic, where, on tacking and taking advantage of the south-east trades, she would once more reach the equator. From this point northwards the vessel would be opposed by the north-east trade winds, against which she would need to tack across the Atlantic until she arrived within the region of the south-west anti-trade winds, which with the Gulf Stream Drift would in due course assist her in getting back home again. The possible course taken by sailing ships in navigating other parts of the oceans may be readily deduced by studying a chart of the currents and prevailing winds for the region.

Currents in Enclosed Seas.—In the great inland seas of the globe there is no well-defined system of circulation of the waters like that explained for the great oceans. This is because of their comparatively small area. There is, however, a constant flow either inwards, if the sea needs replenishing; or outwards, if the supply it receives from the land is in excess of that lost by evaporation. The two most important enclosed European seas are the Baltic and the Mediterranean.

Currents of the Baltic.—The Baltic Sea is very shallow. Its average depth is only 20 fathoms, and on its southern shores its extreme shallowness makes navigation very difficult. In these parts the coast is very sandy, and most of the large German rivers enter it through great lagoons, The deepest part of the sea lies to the east of the island of Gothland. Its waters are almost fresh, since a very large proportion of the land mass of Central and North-east Europe is drained into its basin. Furthermore, owing to its situation in the north temperate zone, the amount of evaporation from its surface is small, compared with the river-supply. For these reasons its density is low, when compared with sea-water; the density of the water at the head of the Gulf of Bothnia is only 1·002—almost equivalent to that of fresh water. There is, therefore, an outward surface flow of the less dense surplus water through the narrow passages leading into the Cattegat, while a weak under-current, due to the greater density and salinity of the Cattegat, makes its way inwards. Its low density and placid nature—for the tidal wave never reaches farther inwards than Gothland—cause it frequently to be frozen over in hard winters. If the Baltic were as saline as the Mediterranean, it would probably never freeze.

Currents of the Mediterranean.—The waters of the Mediterranean, the largest inland sea in the world, are of great salinity; because (*a*) it receives very few rivers in comparison with its size, and (*b*) the evaporation by hot winds is very great (see p. 170). The evaporation carries off three times as much water as the rivers bring down. Moreover, the rainfall in its basin is very small. Its density is, therefore, greater than that of the Atlantic, so that it possesses two strong surface currents of water of less density—one entering it through the Strait of Gibraltar and the other through the Dardanelles—to make up for the deficiency lost through evaporation. Slight outward movements of the denser water of the Mediterranean set in underneath these two surface streams. A further result of the narrow entrance to the Mediterranean at the Atlantic end is that the tides in this sea are hardly perceptible; they rise as a rule only a few inches, and so allow the inflowing rivers to form large deltas (see p. 262).

EXERCISES

1. Write a short note on each of the following and show that you understand their distinguishing characteristics: waves, tides, drifts, and currents.

2. Account for the clockwise direction of the ocean currents in the northern hemisphere, and the anti-clockwise direction in the southern hemisphere. Give also examples of land masses that cause deflection or bifurcation of currents.
3. "The 'brave west winds' give rise to an easterly drift right round the world, crossed in many places by tongues of cold water shot out from the icy regions of the Antarctic." Expand this.
4. Describe separately the vertical and the horizontal circulation of the ocean. State the causes in each case.
5. Describe the currents of the Atlantic Ocean; and explain how ocean currents are supposed to be caused. (Camb. Sen. Loc.)
6. How are the chief ocean currents affected by the prevailing winds? Illustrate your answer by a diagram showing the ocean currents and the prevailing winds of the Atlantic.
7. Give a description of the stream and drift currents of *either* the Indian Ocean *or* the Pacific Ocean north of the equator. (Oxf. and Camb. Lower Cert.)
8. Describe the cause of any one of the great cold currents of the oceans, and its influence on the climate of the regions affected by it. (Oxf. and Camb. Lower Cert.)
9. Describe the winds and currents of the Indian Ocean in July. Point out how they affect the course of sailing vessels travelling from South Africa to Calcutta. (Oxf. and Camb. Lower Cert.)
10. Describe the stream and drift currents of the South Atlantic, pointing out their influence upon the climates of its coasts. (Oxf. and Camb. Lower Cert.)

11. Discuss the origin, character, and influence of the chief cold oceanic currents. (Lond. Univ Inter. Science.)
12. Describe with sketch-maps the general direction of the principal ocean currents between the tropics. (Oxf. and Camb. Sch. Cert.)
13. Give an account of the circulation of the surface waters of the Atlantic north of the equator, distinguishing between stream and drift currents and between warm and cold currents. (Oxf. and Camb. Sch. Cert.)
14. Draw a map with the south pole as the centre to show the surface currents of the ocean in the southern hemisphere. Explain those of the South Atlantic. (Oxf. and Camb. Lower Cert.)
15. Describe the route usually followed by sailing ships on the voyage from England to India. Point out the relation of the different parts of the course to prevailing winds and currents. (Oxf. Sen. Loc.)
16. Speaking generally, the oceans north of the equator show a circulation as if the water had been stirred in the direction of the hands of a watch, and those south of the equator show an opposite circulation.

    Describe the currents of the Atlantic Ocean, and show how far they are in accordance with the above statement. Illustrate by a sketch-map, and indicate on the map (*a*) a warm current, (*b*) a cold current. (Oxf. Sen. Loc.)
17. Explain why there is a surface current from the Indian Ocean into the Red Sea and a return current outwards along the bottom.

    Mention any enclosed seas with (*a*) a similar, (*b*) an opposite circulation, and give reasons. (Oxf. Sen. Loc.)

18. Sailing ships go from England to New Zealand by the Cape of Good Hope, but return from New Zealand to England by Cape Horn. What are the geographical reasons which account for this difference in the outward and homeward routes? (Oxf. Jun. Loc.)

19. Give some account of the present state of knowledge with reference to the relation existing between prevailing winds and surface currents in the open seas. (Civil Service, Eastern Cadets.)

20. Describe the extent and course of the ocean current commonly known as the Gulf Stream. State why it is so named, whether the reason is in accordance with fact, and if not, how it is at variance with fact. (Camb. Jun. Loc.)

21. Give a list of the principal ocean currents. State the causes of them and discuss their influence upon climate and on commerce. (King's Scholarship.)

CHAPTER XX

Sea-depths and Ocean-bed

Oceanography.—Of late years much has been discovered respecting the great oceans. The information gathered by survey-ships, fitted with the most modern appliances for survey work, has been recorded and tabulated on charts which show (*a*) the depths, (*b*) the character of the ocean-floor, (*c*) the temperature of the sea in different parts and at various depths, (*d*) the prevailing currents of the great oceans. The nations that have borne a prominent part in this very important work, known as **Oceanography**, are Great Britain, the United States, and latterly Germany. One of the first surveys made was undertaken by H.M.S. *Challenger* in 1872–6. This vessel was sent out and equipped at the expense of the British Government, and the knowledge gained respecting the great oceans—especially the Atlantic and Pacific—more than justified the need of such an expedition.

The Lead-line.—The depths of the ocean were determined on the *Challenger* expedition by means of an apparatus called the "Hydra" sounder. An elaborate appliance of this kind is not essential to plumb the depths of shallow seas, or to "take soundings," as it is called. A simple line marked in fathoms is sufficient. To this line is attached a lead weight—lighter or heavier according to the depth to be plumbed, and in the bottom of the lead is cut a hollow which is filled with tallow, to which the various substances at the sea-bottom adhere. This method of determining depths may be employed for depths up to 1,000 fathoms. For example, it might be used for finding the depths of the North Sea or the Sea of Azov (average depth 42 feet) and give good results. For greater depths it is not suitable, because of the effect of currents, and the difficulty experienced in making a weight of this kind sink. Even if a sufficiently heavy weight is let down to keep the line taut, it is difficult to bring it back again. Hence the "sinker" system described in the next paragraph. If a lake or river is within easy access, an interesting exercise is to make a lead-line like that described, and by means of it take soundings from a boat at different points. Then draw a map of the lake and insert the depths thus obtained in their relative positions. Contour lines (see Chap. XXXVI) might then be drawn on the map at intervals of 5 or 10 feet, vertical depth (fathom measurements are only applied to sea-depths), and the space between each successive pair of contours coloured according to the method employed in bathygraphical maps. A section may then be constructed to show the rise and fall of the bottom of the lake.

Deep-sea Soundings.—The "Hydra" apparatus used on the *Challenger* expedition consists of a brass tube with cylindrical weights called "sinkers" attached. The tube is hollow and fitted with valves, so that when it strikes the bottom of the ocean the valves open and matter from the ocean-bed enters. On the instrument being withdrawn, the valves close automatically and the matter remains within the tube until it is taken out for analysis on reaching the surface. The instrument is also provided with a deep-sea water-bottle fitted with automatic stop-cocks which open and allow

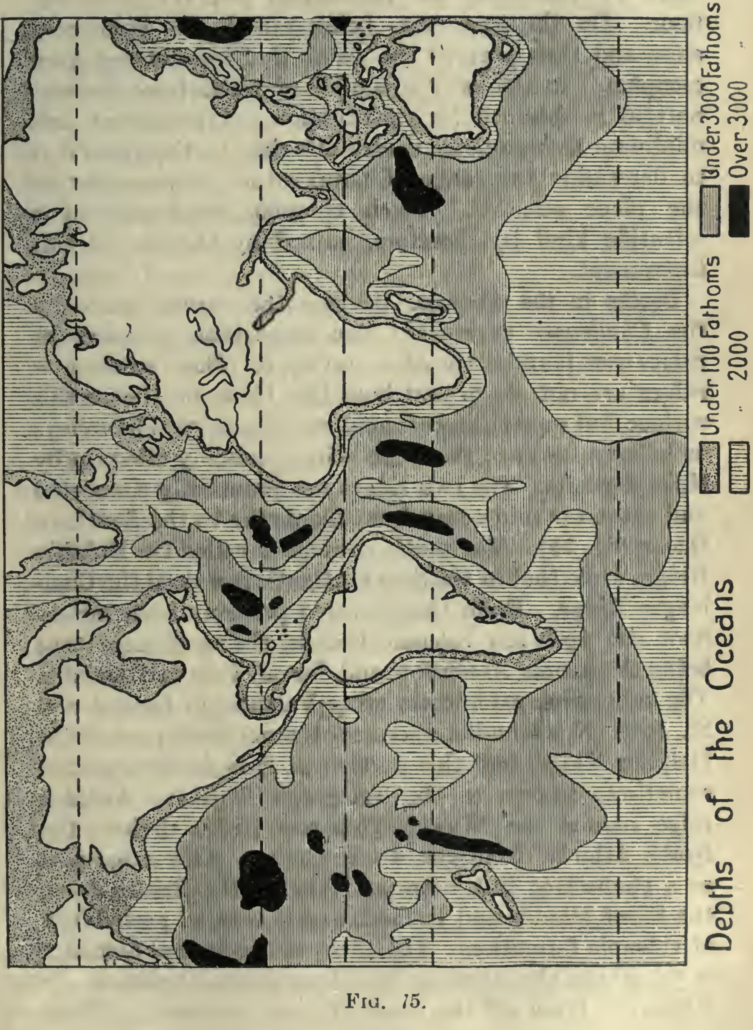
Depths of the Oceans
Under 100 Fathoms
2000
Under 3000 Fathoms
Over 3000

FIG. 75.

water to enter while the instrument rests on the ocean-floor. On the apparatus being raised, the stop-cocks close and thus prevent the water that has entered from escaping. In this way a sample of water from the sea-bottom is obtained for examination. A maximum and minimum thermometer is also attached to the apparatus to determine the range of temperature of sea-water at the place selected. Much valuable knowledge of a scientific kind is, therefore, gained by the use of this instrument.

Depths in the Atlantic.—During the survey made by the *Challenger* expedition two important plateaux or ridges were found in the Atlantic Ocean. These ocean-floor ridges are not sharp and bold like those on the earth's surface, but smooth and covered with deposits. The valleys or hollows between them are being gradually filled up by these deposits. The two ridges are practically connected and extend in mid-ocean from the Arctic to the Southern Ocean (fig. 75). The northern ridge is called the Dolphin Ridge, while that in the South Atlantic is named the Challenger Ridge. From this elevated portion of the ocean-floor rise up a few volcanic islands, the most important being the Azores, Ascension, and, far off, Tristan d'Acunha. The submarine cable connecting Valentia in Ireland and St. John (Newfoundland) crosses the northern part of the Dolphin Ridge, and this portion of it is in consequence sometimes known as the Telegraph Plateau. Another ridge named the Wyville-Thomson Ridge divides the North Atlantic from the Arctic Ocean. This ridge acts as a connecting link between Norway, the British Isles, the Faroë Islands and Iceland, and it is in all probability of volcanic formation. The effect of the central plateaux is to divide the Atlantic into four great " hollows " or " basins " lying off the coast of each continent. These "hollows" have a mean depth of 3,000 fathoms, but in certain parts are much deeper. In each basin there is a large "trough" or "deep." The deepest of these is the **International Deep,** situated to the east of the West Indies. It was here, not far from the island of St. Thomas, that the *Challenger* recorded the deepest Atlantic sounding—one of 4,561 fathoms.

Depths in the Pacific.—The depths of this ocean have not been explored to the same extent as the Atlantic. We know, however, that there are two great longitudinal ridges traversing it, both starting from the Southern Ocean and running northwards (fig. 75). One is called the Eastern World Ridge, the other the Western World Ridge. These ridges enclose a "hollow" or "basin" of great extent, having a mean average depth of about 2,000 fathoms. Here and there within this basin are wide troughs descending to enormous depths. One of these troughs—the **Tuscarora Deep**—is situated off the east coast of Japan, and it was here that the American survey-ship *Tuscarora* sounded a depth of 4,655 fathoms. H.M.S. *Penguin* discovered another trough off the Kermadec Islands, and recorded a depth of 5,155 fathoms. Up to 1912 it was thought that the sounding of 5,269 fathoms made by the American vessel *Nero* in 1906 near Guam off the Ladrones was the deepest part of the ocean, but this depth was in that year exceeded by over 80 fathoms in a sounding recorded by the German survey-vessel *Planet,* 40 nautical miles north-east of Mindanao. This depression, known as the **Planet Deep,** is probably the continuation of another great trough in this part of the Pacific discovered by the same ship in the early part of the same year. On the north, Bering Strait—which is very shallow—cuts off the Pacific basin from the Arctic.

Depths in the Indian Ocean.—This ocean consists of one great "basin" almost equally divided into two parts by a narrow ridge running from Ceylon to Madagascar (fig. 75). From this ridge rise several groups of small islands, including the Seychelles and Isle de Réunion. At the extreme end of South Africa is another ridge that stretches eastward, narrow at first but expanding as it proceeds, till, on reaching about the meridian of 90° E., it attains its greatest breadth. From where this ridge ends to the coast of Australia the central basin extends southwards. The greatest depression of the ocean is found to the west of Java. From here a trough extends southwards almost to the north-west coast of Australia, and then by a series of pits among the islands of the East Indies continues into the Pacific Ocean. The contours of this ocean suggest a former connection between India, Madagascar, and the mainland of Africa.

Ocean Deposits.—Sea-water contains in solution small quantities of oxygen and carbonic acid gas. Upon the latter of these and upon some of the salts in the water marine plants live, changing these simple substances into very complex plant material. The smaller marine animals then feed upon this plant material, at the same time either extracting sulphate of lime from the sea-water and changing it to carbonate of lime, or taking carbonate of lime direct from the sea-water. The carbonate of lime (chalk) appears in the bodies of these animals in the solid form usually called the skeleton, but much more properly called the framework or the shell. Whatever form the solid part takes, whether an enclosing shell armed with spicules, or a shell perforated by tiny apertures, or a framework without an enclosing shell, the general name of *test* applies to every one. The tests always remain after the animal has died and decayed.

Another substance extracted from the sea by both plant and animal life is silica, which, like carbonate of lime, appears in the solid form as tests of wonderful complexity and beauty. Swarms of minute organisms float along the surface waters of the ocean, for ever doing this work of lime and silica extraction and shell manufacture. To these minute organisms is given the general name of *plankton*,* which distinguishes them from coast forms of life and bottom forms. The death and decay of the plankton results in a continual rain of tests upon the floor of the deep ocean. Accordingly, over large areas of the deep ocean, the sounding instruments bring up material composed almost entirely of such tests. All such deposits are known as *oozes*.

Various Forms of Oozes.—The three predominating tests are :

Animal	1. Globigerina, minute round, network tests composed of carbonate of lime, and consequently known as calcareous. Mixed with the carbonate of lime are traces of oxides of manganese and iron. (In tropical seas and oceans occur tests of pteropods and heteropods, tiny molluscs and both calcareous.) 2. Radiolaria, minute spiky tests composed of silica, and consequently known as siliceous.
Plant	3. Diatoms, minute shuttle-shaped plants, also siliceous, usually found in the colder oceans.

The oozes are known by the name of the predominating tests, *e.g.* globigerina ooze, diatom ooze, and so forth. Another important constituent of the oozes is volcanic

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* Floating drift life.

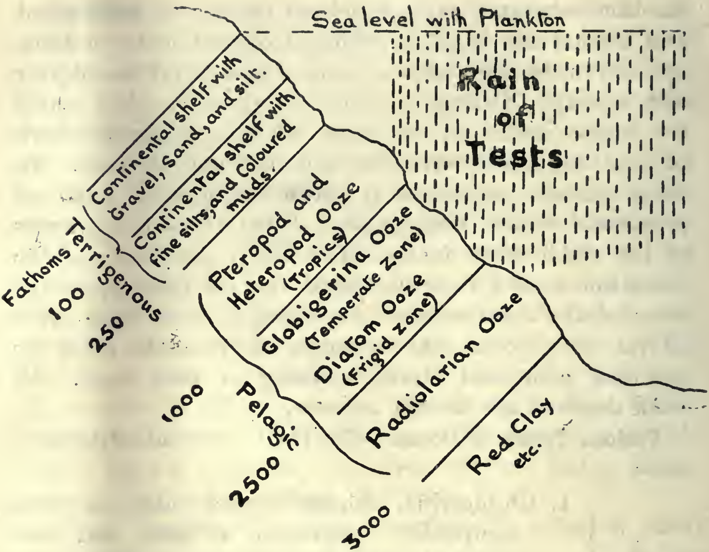

Sea level with Plankton
Rain of Tests
Continental shelf with Gravel, Sand, and silt.
Continental shelf with fine silts, and Coloured muds.
Pteropod and Heteropod Ooze (Tropics)
Globigerina Ooze (Temperate Zone)
Diatom Ooze (Frigid Zone)
Radiolarian Ooze
Red Clay etc.
Terrigenous
Pelagic
Fathoms
100
250
1000
2500
3000

Fig. 76.

and meteoric dust, which is always settling down in clouds all over the ocean-surface, and thence slowly sinking down to the very deepest depths. The amount of carbonic acid in the ocean-waters increases with depth. At a certain depth (about 2,000 fathoms), therefore, there is sufficient carbonic acid to dissolve the calcium carbonate of the globigerina tests. So that beyond that depth globigerina ooze ceases. Silica can remain as a solid at a greater depth than carbonate of lime, but it also dissolves back into the water before reaching the deepest basins. Hence in the deepest parts of the ocean the only ooze constituents are the volcanic dust, and a small quantity of oxide of iron and oxide of manganese. Hence the oozes found upon the ocean-floor are, roughly speaking, distributed as follows (fig. 76):

1. In the shallower parts of the ocean deeps a mixture of globigerina (limey), radiolarian (siliceous), and volcanic dust. This is called globigerina ooze.
2. In the deeper parts the globigerina tests practically disappear, leaving only radiolaria and dust fragments. This is called radiolarian ooze.
3. In the deepest abysses only the volcanic and meteoric dust mixed with sharks' teeth, oxides of iron and manganese is found. This is called abyssal red clay.

Round the margins of the oceans upon the continental shelf (see p. 324) is found a totally different kind of deposit, derived from the land and consisting of fine clay, mud, sand, shingle, gravel, and sometimes coral fragments. The finest mud and clay, being the last to settle, are carried farthest out. The most abundant of the finer deposits is "blue mud," the blueness of which is due to the presence of sulphide of iron. The coarser material is usually heaped up along the actual coast-line in the form of the well-known sand and shingle of the shore. These deposits brought down from the land by rivers are called **terrigenous**; the oozes deposited in the deep ocean are called **pelagic.**

EXERCISES

1. Rivers bring down stones, sand, and clay in suspension, and lime in solution. How are these various materials deposited on the ocean-floors?
2. Describe two deep-sea deposits which are being formed of the remains of animals or plants. (Camb. Jun. Loc.)

3. Give a general description of the deposits which cover the bottom of the sea. (Oxf. and Camb. Sch. Cert.)
4. Compare and contrast the leading features of the Atlantic and Pacific Oceans in relation to depth, sea-bed contour, outline and nature of land margins, and receipt of rivers. (Lond. Univ. Inter. Science.)
5. Describe the form of the deep-sea bottom as compared with that of dry land. (Camb. Jun. Loc.)
6. What is shingle? Where is it generally found, and how is it formed? (Camb. Jun. Loc.)
7. Describe the form of the floor of the North Atlantic. How do the deposits formed in the centre of the ocean differ from those formed on its margin?
8. Describe the configuration of the floor of the Atlantic, and illustrate by a sketch-map and vertical section. (Central Welsh Board.)
9. What are the mean depths of the Atlantic, Pacific, and Indian Oceans? Which of these oceans is said to be the deepest?

CHAPTER XXI

Salinity and Temperature of the Sea

Sea-water and River-water.—Sea-water differs from fresh water in that it contains a large percentage of sodium chloride or common salt. It must not, however, be assumed that water commonly spoken of as fresh contains none of this salt. All river-water contains many kinds of salts in solution dissolved from the land over which the rivers flow. The amount is, however, small and cannot be detected on tasting the water. The dissolved solids held in river-water vary from 2 to 50 grains per gallon, the former where the river flows over hard beds of rock like granite, the latter where it flows over more easily dissolved rocks like limestone. On the whole, river-water contains on the average about 12 grains of dissolved solids per gallon. On analysis this dissolved matter in river-water from a limestone region has been found to be made up as follows:

		Per cent.
Carbonates	of calcium	43
	of magnesium	15
Sulphates	calcium	4·5
	sodium	4
	potassium	3
Chloride sodium		2
Silicon oxide (silica)		10

On analysis sea-water has been found to contain:

		Sea	Rive
		Per cent.	Per cen
Carbonates	calcium	·1	43
	magnesium	·2	15
Sulphates	calcium	4	4.5
	sodium	Traces	4
	potassium	2·5	3
	magnesium	5	—
Chloride sodium		78	[illegible]
Silicon oxide (-silica)		—	[illegible]

Very many other salts occur in both analyses in very small quantities.

A comparison of the two tables shows us: (*a*) that all the silica and nearly all the calcium carbonate in river-water have disappeared in sea-water. What has become of them? The countless organisms of both animal and plant life that exist in the ocean have used them up to build their shells. (*b*) The sulphates show a small change; but the great difference is (*c*) that in river-water the carbonates predominate and cover or disguise the sodium chloride, whereas in sea-water the carbonates are practically gone, the silica is gone, and common salt predominates. To state this in another way: river-water contains samples of many solids with much of some; sea-water contains much of sodium chloride, with little of others. Or sea-water is river-water with the "fresh" salts used up except one, which grows in proportion, *e.g.* common salt. It is estimated that sea-water salts average about 3·5 per cent., that is to say, in every 100 lb. of sea-water there are 3·5 lb. of dissolved salts. Furthermore, it is clear that the salinity of the sea is mainly due to the salts it receives from the rivers flowing into it. The great percentage of common salt in sea-water increases its density as compared with river-water, but because of the effects of (*a*) evaporation and (*b*) temperature, the density of the ocean is not the same in all parts.

Evaporation and Density of the Sea.—Take a saucer of salt water, and evaporate the water. Salt crystals will be observed to have been left behind on the surface of the saucer. Now take a saucer of muddy water and evaporate the water. A thin coating of matter is seen to lie on the surface of the saucer. This is the mud that was held in suspension by the water, but has been left behind through the action of evaporation. Evaporation is constantly taking place over the oceans, and the matter held in suspension and in solution by the water is, after evaporation, left behind, and the density of the ocean is thus increased. The salinity of the sea is, therefore, more marked where evaporation is greatest. It is clear that the greater the salinity, the greater the density, provided that the sea-water is measured at a certain standard temperature. The standard temperature at which the density of sea-water is generally measured is 60° F. When a number of samples of sea-water have been taken from different parts of the ocean and their densities found, the mean of all the results is spoken of as the mean density of sea-water. This is usually reckoned as 1·0275. It means that if a vessel were to contain exactly 1,000 grains of pure water at a temperature of 60° F., the same vessel would hold 1027·5 grains of sea-water, in which there would be 3·5 per cent. of salts in solution. In enclosed seas situated in warm climates, like the Mediterranean, the water is of great salinity and of high density. But seas in cool climates, especially those receiving much river-water, have small salinity and low density. The water of the Gulf of Bothnia has a density of only 1·002; hence the rapidity with which its surface freezes in winter. In the tropics, in the open ocean, the salinity of the water is not so high, because the water expands on being heated and its density is thereby decreased. Again, the tropics are situated in a great rain-zone, and the density of the surface water is relatively small owing to the excessive rainfall. This is especially the case in the region known as the *Doldrums*, which extends some distance north and south of the equator. In the temperate zones there are certain belts of heavy rainfall (see Chap. XVI) in which the salinity of the ocean is similarly affected. The result of freezing water is to cause the salt to be crystallised out, and deposited in the same way as that explained in the case of evaporation (see p. 305). The masses of ice to be met with in the polar seas contain very little salt, and along the northern shores of Siberia, where the marshy tundras are frozen over, a deposit of salt may be obtained on the surface of the ground by breaking through the coating of ice. During the summer months there is in the northern hemisphere a constant flow southwards of icebergs and ice-floes. These reach the border of the temperate zone, where they are melted. This fresh-water supply and the rain keep the ocean salinity down in those parts. Most inland seas are very saline, the Dead Sea and Lake Urumiah in Persia being especially noteworthy in this respect (see pp. 451-2). These lakes receive little river-water to compensate for their loss through evaporation. This is likewise the case with the Mediterranean and Red Seas, but here the deficiency is made up by a constant supply of ocean-water, which flows inwards as a surface current. There is also in both seas an under-current of great salinity flowing outwards. That of the Mediterranean can be traced in the Atlantic as far west as Madeira.

Pressure of Sea-water.—From the fact that, as in the case of the atmosphere, pressure varies with the column of air above us, it is apparent that the effect of an increase in depth in the oceans is to increase the pressure on the lower layers of water. It has been calculated that the pressure of water is equivalent to a pressure of one ton to the square inch for every mile of depth. Water is, however, only slightly compressible, and the compression due to depth is not of great moment. Still, the molecules of which the water at the bed of the ocean is composed are in some degree pressed more closely together and thereby result in an increase in density. The very slight effect that pressures have on water density may be gauged from the fact that it has been found that a depth of two miles increases the density only by about $\frac{28}{1000}$. 240 cm ∴ less per 100,000 cm.

Variation in the Temperature of the Sea.—The surface (Prob. much water of the great oceans undergoes considerable variation in temperature. It ranges from 80° F. at the equator to 28° F. near the poles—a greater variation than that of the land surface. If sea-water falls below 28° F. (*i.e.* 4° below the freezing-point of fresh water) it freezes, so that the temperature of the sea is never found below that point. Of course, within the Arctic circle the temperature is so low that the surface water is turned into ice. There is, however, a regular decrease from the equator until the ice-line limit of the polar seas is reached. The subject of the temperature of the seas and oceans may be treated under two headings: (*a*) **Horizontal Distribution of Temperature**; (*b*) **Vertical Distribution of Temperature.** In any inquiry into the causes which account for the distribution of temperature in the oceans, the following facts should not be lost sight of:

(*a*) Warm water is less dense than cold water, and therefore lighter.

(*b*) Salt water is denser than fresh water, and therefore heavier.

(*c*) Warm fresh water is much lighter than cold salt water.

Horizontal Distribution of Temperature.—The *normal* distribution depends primarily on **latitude,** although there are many irregularities due to winds, currents, and rivers. In summer the temperature of the surface water in the northern hemisphere is much higher than in winter. For example, a difference of at least 20° F. has been recorded off the coast of Newfoundland between the summer and winter temperatures. This difference is not wholly due to the seasons, for the Gulf Stream and the Labrador Current have an important effect on the temperature of the water. In a more northerly latitude near the Arctic circle the sea is almost frozen during the depth of winter, while in the summer it is entirely free from ice except for icebergs passing on their way southwards. The range between summer and winter temperatures in the southern hemisphere is not so marked because of the absence of any great land mass that might prevent the water of the Southern Ocean from entering the other large oceans. In the tropics the least variation is to be observed. Here the surface temperature is almost the same for all the year round—the mean surface reading being about 80° F. The area over which this mean average temperature extends stretches from about 20° N. to 20° S. latitude in the Pacific and from 10° N. to 10° S. latitude in the Atlantic. Nowhere in the open sea does the surface temperature exceed this point, although the surface water of some enclosed seas rises to 90° F. or even 100° F.

Temperature and Latitude.—The warmest parts of the ocean are, obviously, those within the tropics. North and south of the tropical zone there extends in each ocean another large belt in which the surface temperature decreases from 80° F. to 60° F. This belt in the North Atlantic lies between the parallels of 10° N. and 40° N. latitude; in the South Atlantic between the parallels of 10° S. and 30° S. latitude. It must be remembered that, although there is a gradual decrease from these belts to the poles, the decrease is not proportional to the latitude. Many irregularities, such as (*a*) prevailing winds, (*b*) the difference of density of the water, (*c*) currents, and (*d*) rivers, account for this variation.

Surface Temperature and Winds.—It will have been noticed from the figures given that the 60° limit of surface temperature is nearer the equator in the South Atlantic than in the North Atlantic. This is explained by the fact that the south-easterly winds cause the North Atlantic currents to move from the warmer regions across the equator, and thus the temperature of the northern part of the ocean is raised. Another remarkable feature due to the action of wind is that the water that washes the east coast of the large continents in the tropics is of a higher temperature than the water that washes the west coast. We may best explain this by supposing that the diagram (fig. 77) represents a lake of which the surface water is perfectly still, there being no wind to disturb

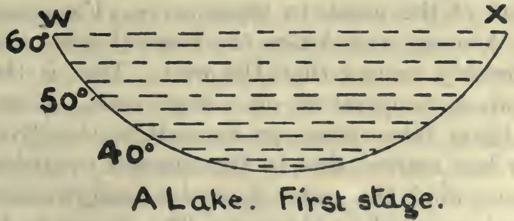
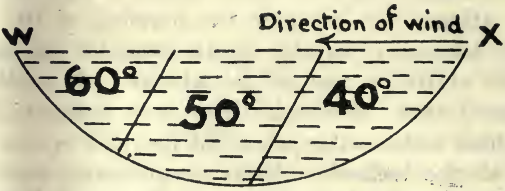


FIG. 77.

it. Assume that while in this state the temperature of its water at *X* is taken and found to be 60° F. on the



A Lake. Second Stage.

FIG. 78.

surface, 50° F. farther down, and 40° F. at the bottom. Now let a wind blow on its surface in the direction of the arrow (fig. 78). The effect of this will be to blow the warm surface water across towards *W*. To take the place of the water thus removed there is a rise of the lower and cooler layers. These in their turn become warmed and are blown across towards *W*. Thus the system of temperatures becomes as seen in fig. 78. Hence an *on-shore* wind warms the land and an *off-shore* wind cools the land. In like manner the north-east and south-east trade winds assist in causing the warm currents near the equator to flow towards the east coast of the large continents, and so raise the temperature of the ocean in those parts. For example, in South America and Africa the tropical east coasts are considerably warmer than the west. That is the effect of wind on temperature on a large scale. Exactly the same thing takes place on a small scale. Every seabather has noticed that in the summer time during an off-shore wind the water is cooler, and warmer when an on-shore wind is blowing. The reason is that the on-shore wind drives in water that has been heated over a large area. This warm water banks up to some depth and displaces the cooler water which flows as a gentle undercurrent seaward. An off-shore wind, on the other hand, pushes the warm surface water seaward and the colder water from underneath rises up to take its place.

Surface Temperature and Density.—Since the water of the North Atlantic is warmer than the South, there is more evaporation in the north than in the south. This rapid evaporation, due to the south-east trade winds driving the warm surface water before them, increases salinity and consequently the water in the north is of greater density. Because of its high density the warm water sinks more rapidly than it does in the South Atlantic. Hence heat is transmitted to the lower layers. In the case of the Pacific the same thing is true—but for a different reason. Of all the oceans the Pacific as a whole is the coldest, because it is more completely exposed to the icy waters of the Antarctic. At the same time it is of a comparatively low density, due to the very large area of its surface that is situated in a zone of heavy rainfall. Especially is this so in the northern half, owing to the effect of the prevailing winds and currents. This constant supply of fresh water keeps the surface water of low density and therefore colder.

Temperature and Currents.—Currents have a very important influence on the surface temperature in certain parts of the ocean. There is a constant flow of water from the polar seas towards the warmer parts of the ocean. These surface drift-currents lower the temperature of the northern and southern portions of the great oceans. They make themselves felt as far south in the northern hemisphere as the parallel 40° N. latitude, and as far north in the southern hemisphere as the parallel 40° S. latitude. On reaching these limits they descend, because they meet warmer waters, which are of less density because of their warmth. On the contrary, warm drift-currents like the Gulf Stream in the North Atlantic and the Kuro-siwo in the North Pacific tend to raise the temperature of those parts of the oceans through which they flow. The influence of the Gulf Stream Drift is best seen on the surface water surrounding the British Isles. Off the west coast of Ireland the average temperature of the sea is over 40° F.

Temperature and Rivers.—Rivers in summer have the same temperature as the land over which they flow. Therefore, river-water has during that period of the year a higher temperature than the sea. In winter the temperature of the land is lower than that of the sea (see p. 154). Hence river-water is then colder than the sea. Large and swift rivers like the Amazon, Mississippi, and Congo send forth their waters into the sea for many miles from the land. The river-water, being fresher and less dense than the surrounding sea, may from its muddy appearance be easily discerned floating on the surface until it is lost through evaporation or mixes with the ocean.

Vertical Distribution of Temperature.—A definite knowledge of the vertical distribution of temperature of the oceans is even more important than a knowledge of the horizontal. It is obvious to everyone that the temperature of a large volume of water *varies with the depth.* Consider a lake in which the surface water is exposed to the sun's rays. Now, since water is a bad conductor of heat, the sun's rays do not penetrate far downwards, so that only those layers that are near the surface can be affected by them. For this reason the surface layers are warmer and less dense than those underneath. It is so with the ocean, as can be seen from a study of the graph (fig. 79). This was made on the *Challenger* expedition, and shows the decrease of temperature for vertical depths at varying intervals in the South Atlantic. From it we see quite plainly that there is (*a*) a *rapid* fall from 58° F. to 48° F. in the first 200 fathoms down; (*b*) a further fall to 40° F. at 500 fathoms; (*c*) a constant *gradual* fall to 35° F. after 600 fathoms, then very little change. From this we may gather that the temperature of the bulk of the ocean is below 40° F., and that the ocean really consists of a thin layer of warm water lying on the top of a vast volume of cold water. The decrease in temperature from the surface downwards is nearly the same for all latitudes, but is most rapid in the warmer parts of the globe. In the case of the lake just cited (fig. 77), suppose that it was only 20 feet deep. In summer its waters might well be warmed throughout by the sun. Reasoning thus, you may be inclined to suggest that as the sun has been shining on the surface of the sea for millions of years, the warmth of its rays should have reached the bottom by this time. But this is not so, and the explanation is to be found in the existence of **convection currents**—sometimes spoken

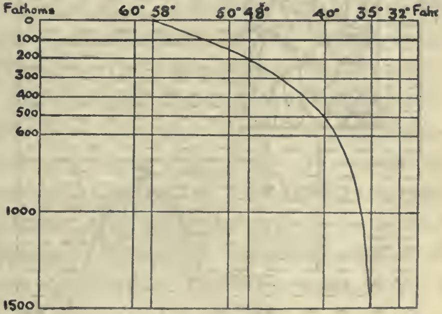


FIG. 79.

of as the **Cold Polar Creep**—that slowly make their way, near the ocean-floor, flowing from the poles towards the equator (see p. 276), and constantly cooling the under layers of the ocean.

Temperature of Enclosed Seas.—(i) Procure a small rectangular trough fitted with a gauze net, as in fig. 80, and place a ridge of clay (C) in the form of a triangular prism across it so as to allow the surface water to flow over. Fill the trough with warm water and place ice in the gauze net (I). Next take the temperature of the water at X, X_1, X_2, X_3, and compare the readings. You will observe that the difference in the readings between X and X_1 is much greater than the difference between those taken at X_2 and X_3. In other words, the cold water from the ice has crept along the floor of the trough, but has not been able, because of the greater density of the cold water, to surmount the barrier of clay and reach X_3. This experiment is helpful in illustrating two important facts respecting the movements of waters in the oceans: (1) It explains why there is such a marked difference between the vertical distribution of temperature in (*a*) enclosed seas shut off from the ocean by a sill and (*b*)

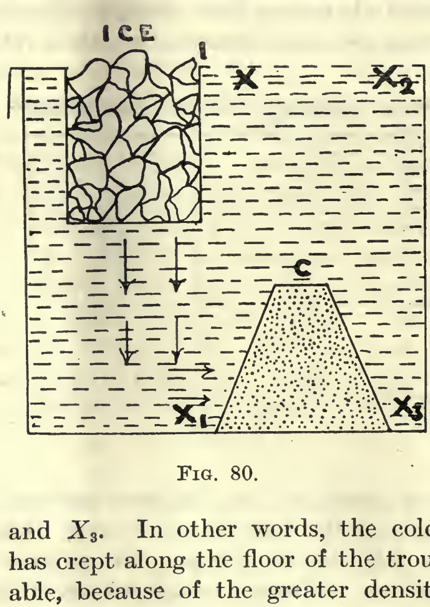


Fig. 80.

outside in the open ocean. (2) It shows us definitely that *convection currents do not cause ocean currents*, because there are ridges on the ocean-floor—some of great height—that the cold water must cross if it is to assist in the formation of currents near the equator.

Temperature of Enclosed Seas.—(ii) As in the open ocean, the temperature of enclosed seas decreases with depth to a certain minimum, and then remains steady for all greater depths. But in enclosed seas the minimum is both higher than that of the open ocean and sooner reached. Most enclosed seas have a ridge or sill at the ocean entrance (usually the rim of a foundered basin). This sill prevents the cold bottom water of the ocean from entering the sea. Therefore the temperature of the water of the enclosed sea suffers no decrease beyond the depth of the sill. At the Strait of Gibraltar the sill of the Mediterranean is 200 fathoms deep (fig. 81). The surface temperature of both the Atlantic and the Mediterranean is 76°. At 200 fathoms the temperature of both has dropped to 55°. Beyond this depth the temperature of the Atlantic continues to decrease to a minimum of 35°;

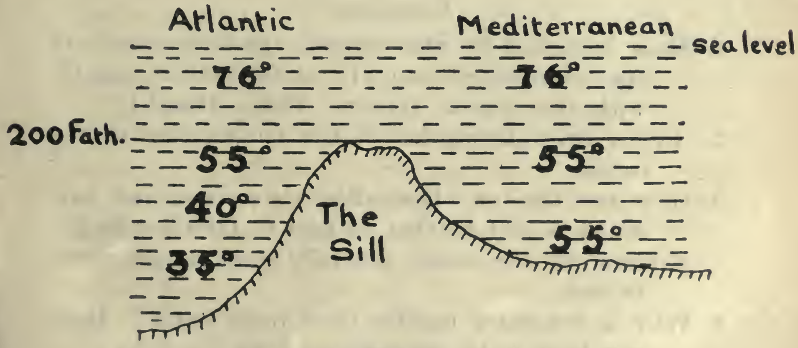


FIG. 81.

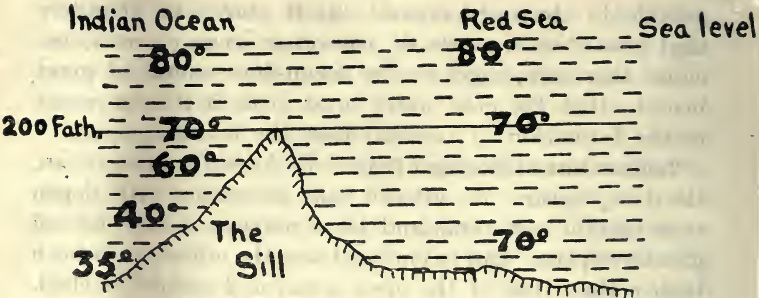


FIG. 82.

but the temperature of the Mediterranean continues at 55° to the bottom. Again, at the Strait of Bab-el-Mandeb, the sill of the Red Sea is 200 fathoms deep. The surface temperature of both the Red Sea and the Indian Ocean ranges from 80° upwards. At 200 fathoms the temperature of both has dropped to 70°. Then while the Indian Ocean continues to decrease to the minimum of 35°, the Red Sea remains at 70° to the bottom (fig. 82).

EXERCISES

1. Show how, and to what extent, the temperature of the ocean waters varies (*a*) at the surface, and (*b*) with the depth. (Central Welsh Board.)
2. Give a brief description of the temperature of the ocean.
3. How does the sun's heat affect the oceans, and how do we benefit by that on land? (Civil Service.)
4. Explain why the oceans, generally speaking, are never frozen.
5. Why is sea-water heavier than fresh water? How can fresh water be obtained from sea-water?

6. Compare the temperature and salinity of the surface waters of the ocean west and east of Africa south of the equator, and explain any difference. How far are similar differences observed in the waters off the west and east of South America in similar latitudes? (Oxf. and Camb. High. Cert.)
7. Describe and account for the distribution of temperature and salinity in the North Atlantic Ocean. (Oxf. Sen. Loc.)
8. Describe the nature and direction of the currents flowing through (*a*) the Strait of Gibraltar, (*b*) the Sound, (*c*) the Dardanelles, (*d*) the Strait of Bab-el-Mandeb.

CHAPTER XXII

Elevated Sea-beds and Submerged Land

Elevated Sea-beds.—The ocean-floor is constantly changing. Some portions of it are undergoing a process of elevation, other parts are subsiding. These changes are due to: (*a*) seismic disturbances, slow or sudden, which may either elevate or depress; (*b*) the formation of new matter in the form of oozes (see p. 299), caused by the constant deposition of dead plankton remains, which clearly must elevate. Of these agents, seismic disturbances are most successful in elevating the sea-bed. Marine oozes that once covered the ocean-floor have been slowly lifted up clear of the surrounding water and now form dry land. The internal force that has accomplished this change is still at work and the gradual elevating process is now in progress in many parts of the land masses of the globe. The geological formation of our own country illustrates the changes that it has undergone. For example, Windsor Castle is built on a solid mass of chalk (a sea-bed formation) which rises abruptly from the River Thames. A chalk or cretaceous escarpment may be clearly traced along a line from Dorset through the Chilterns to the east of the Wash on the Norfolk coast. Fossils and remains of marine animals are frequently found in chalk formation, thus showing that the chalk once formed an ooze on the sea-floor. Moreover, beds of sand and sea-shells have been found on the tops of some of our hills. Along the Norwegian coast and west coast of Scotland raised beaches and sea-caves may be now observed many feet above the present level of the sea. The coast-line of northern Russia and Siberia has evidences of comparatively recent elevation (raised beaches with marine shells). The island of Spitzbergen is fringed with raised beaches; and the coastal plain of Mexico is not a smoothly inclined plain but terraced in steps, which indicates its gradual elevation from the sea, each step marking an old sea-beach—a pause, that is to say, in its elevation.

Subsidence.—Subsidence, like elevation, is due to the action of internal forces. Many districts which were once portions of the British Isles have subsided and become submerged. This accounts for the large openings on the east coast of England; for while elevation always simplifies a coast-line, subsidence complicates it. It is subsidence which modifies a coast-line in a much more marked degree than the destructive action of the sea. Indeed our shore-loss by the sea is very much less than our surface-loss by the usual denuding agents—rain, frost, rivers, etc. Sir Archibald Geikie says that "if the continent of Europe is eaten away by the sea at the rate of 10 feet a century (which is above the average), it will require 5,000,000 years for the sea to consume a strip 100 miles wide. But in that time the whole of Europe would be almost worn to sea-level by the atmospheric agents." The east and south coasts of England bear evident traces of subsidence. Many parts have been washed away even in historical times. A strip of land two miles wide in the Holderness district of Yorkshire has been lost since the Norman Conquest. The Dogger Bank and the Goodwin Sands once formed part of the mainland, although there is nothing to support the assertion that the latter formed part of the estates of Earl Godwin. On the contrary, there is strong evidence that they were taken possession of by the sea long before the Earl's time. It is said that the island of Heligoland possessed in the ninth century, in the time of King Alfred, a circumference of 120 miles; by the year 1300 that dwindled down to 45 miles, while to-day its circumference is not much over 8 miles. Another good example which gives evidence both of subsidence and elevation is the Temple of Jupiter Serapis, the remains of which stand on the shore of the Bay of Naples. When the temple was built by the Romans it was of course above sea-level. But three of its marble columns at about 12 feet from the base are filled with holes in which were found the two valves of a marine shell-fish not unlike the common mussel. The shell-fish had bored its way into the marble, just as a "ship-worm" bores into timber, but it could have done so only when the columns were under water. It is thus plain that within historical times this temple stood (1) above sea-level, (2) below sea-level, and (3) above sea-level again. The gradual subsidence of our own eastern coast has become so serious that the Government has taken steps to inquire into it, and if possible find means to prevent the sea's encroachment in several parts. The subsidence which is now actually taking place may possibly extend across the North Sea floor to south-eastern Scandinavia, which country is also subsiding, though, curiously enough, the eastern and western coasts are rising. In fact the whole platform upon which the British Isles stand has subsided, and it was thus that the North Sea was formed. This sea in all probability formed a huge river-basin, and the main stream that ran through it flowed in a northerly direction, had the Elbe and the Rhine for its headwaters, and the Thames and Yorkshire Ouse among its left-bank tributaries. On the right bank, just opposite where the Ouse joined the main river, stood the low Dogger Hills.

Changes due to Volcanic Outbursts.—Volcanic eruptions and earthquakes have also contributed their share to the general changes in the configuration of the sea-bed in certain regions. New islands have suddenly appeared in view in parts of the Pacific, often to disappear as quickly as they appeared, while whole masses of land have been swept away by volcanic outbursts (see p. 380). After severe earthquake shocks and volcanic eruptions large areas of the ocean-bed in the vicinity of the disturbance have been completely altered in form, hollows have been changed into ridges, and ridges into hollows. The great earthquake which almost destroyed Lisbon in the latter half of the nineteenth century entirely altered the configuration of the Atlantic floor off the Portuguese coast. One of the most terrific volcanic eruptions in modern times occurred in August 1883, when a considerable portion of the island of Krakatóa in the East Indies disappeared from view (see p. 380). But the sea-bed has been also added to by volcanic action. In 1867 a shoal was discovered among the Tonga Islands in the Pacific at a point where the surrounding sea was about 1,000 fathoms deep. In 1877 smoke was seen ascending from the surface of the sea over the shoal. By 1885 an island two miles long and 200 feet high had been formed. The island was formed principally of ashes, and was in no long time washed away again by the waves.

Fiords.—Excellent examples of submerged land are provided for us in fiords. There are two great fiord belts in the world, one in each hemisphere, and each some distance from the tropics. The northern belt includes the coasts of Alaska, British Columbia, Greenland, Labrador, Scotland, and Norway. The southern belt includes Southern Chile, Patagonia, and South New Zealand. In these districts the gradual subsidence of the land has allowed the sea to enter, and connect up by narrow gorge-shaped channels, what were formerly inland lakes. At the entrance of each fiord is a submerged sill or barrier, where the water is comparatively shallow. Within the sill the water is very deep. The Sogne Fiord in Norway runs for 100 miles right into the heart of the country, and its many branching arms give us assurance that it is a submerged river or lake valley. The depth of this and other Norwegian fiords is supposed to have been increased by the action of glaciers during the glacial period digging out a still deeper bed. The walls of these fiords are as a rule so sheer that they prevent all communication from one fiord to another except by boat. Such settlements as occur are found generally at the *head* of the fiords and are built on deltas which have been made by inflowing rivers. The same phenomenon also occurs in the fiords of British Columbia and southern Alaska, where the mountain sides, descending steeply to the sea, offer no flat ground for settlements, and hence the towns or villages are built on the delta plains where rivers enter the head of the fiords. On the coast of southern Chile the sides of the fiords are so steep that the Canoe Indians who live there make their canoes their houses and possess no fixed habitation whatever on the land. Most of the fiord coasts are protected by a line of rocky islands, the tops of partially submerged highlands. In Norway this line of islands is called the "Skerry Fence." Between it and the coast is a road called the **lead** which is sheltered and navigable at all seasons.

Rias.—These are submerged or drowned longitudinal valleys. They differ from fiords in that there is no sill at their entrance. Their depth is, therefore, more or less uniform or decreases uniformly from the sea inwards. The ria, or wide and large estuary, may be readily distinguished from the narrow and elongated form of fiord indentation. The Firth of Forth, for instance, is a ria, and offers a striking contrast to the Norwegian fiords. Some of the most remarkable inlets on the north coast of the Spanish peninsula are of the ria type. They are very deep, are bounded by steep cliffs and make fine natural harbours, since the mountain ranges which flank them run down almost at right angles to the sea and so provide excellent shelter from the winds. It was from the Ria of Corunna that the "Most Holy and Invincible Armada" set out in 1588 to attack England.

Changes due to Sea Action.—A complete transformation of the coast-line of each of the continents has been brought about through the constant changes in elevation and subsidence that have just been mentioned. There is still one other factor to be considered in accounting for these changes—the destructive effect of the sea itself upon the land. This action of the sea upon all coasts goes on from year to year, breaking up and splintering into fragments the hardest of rocks. As the sea recedes, these fragments and large quantities of sand and shingle are carried out to sea for some considerable distance. In those parts where the coast is low-lying, and composed of soft material, such as mud and sand, the ravages of the sea are most apparent. Large areas of what once was dry land have been thus in time inundated. This has been the case all along our eastern and southern coasts, and very markedly so along the coast of Holland, which has had in consequence to protect its shore-line by an elaborate system of dykes and walls. Where the coast offers little resistance to the destructive action of the sea, there the sea is shallow. This is due to the rapidity with which the sea makes its way up the beach, and the ease with which it carries back with it on receding the small particles of sand or loose material which composed the coast. Such a coast is generally dotted with sandbanks, and is difficult to navigate.

Continental Shelf.—The area adjacent to the coast-line of any of the continents which is covered by the sea to a depth of from about 100 to 300 fathoms is called the **continental shelf.** Like the ocean-floor, it is fairly smooth and has a gentle slope from the land outwards until its limit is reached. Here there is a very abrupt increase in the steepness of the slope, and the ocean-bed descends suddenly in most cases to a depth of at least 1,000 fathoms. Below this depth the ocean-floor is spoken of as the *Abysmal Area.* The 1,000-fathom contour encloses an area between it and the coast-line of what at some past period of the world's history formed part of the dry lithosphere. Nearly every continental shelf on examination provides evidence of this fact, in the numerous old river-valleys and furrows which lie entrenched upon the shelf. Among the best known of these furrows are the Bottomless Pit off the Niger Delta, the submerged valleys in the Firths of Forth and Moray and those outside the Norwegian Fiords. A narrow shelf presupposes a rocky coast, a wide shelf a flat one. Thus the low plain round Buenos Ayres slips almost imperceptibly beneath the sea, and the depth of water is so shallow for many miles from the actual shore-line that large vessels could not reach the land, if an artificial harbour had not been dredged out. On the other hand, in the extreme north-east of Asia, along the shores of the Bering Sea, there is no continental shelf, and the rocky coast descends in bold cliffs to a surf-beaten beach. On such a coast harbours are few.

The Continental Shelf and Fish.—It is on the continental shelf in various parts of the world that the fishing industry is carried on. We are indebted in no small measure to the sea for a considerable portion of our food-supply. In fact, quite a large proportion of the population living in the outlying districts of the British Isles and those parts of Europe situated near the coast, but otherwise difficult of access, subsists almost entirely on fish. These people always reckon on providing their winter's supply of food in the fishing season, which about our islands is during the summer and autumn months. The home of the Old World's fisheries has for its centre the continental shelf on which the British Isles stand. Here the Dogger Bank, the Goodwin Sands, and the Long Forties are the favourite fishing grounds for all European nations. Round Iceland, too, and among the Lofoden Islands off the Norwegian coast prolific fisheries are carried on. In North America, the Banks of Newfoundland and Nova Scotia and the continental shelf on the west coast of the continent, on which Vancouver and Queen Charlotte Islands are situated, are the most important centres. Bass Strait, separating Tasmania from Victoria, and the sea around the Japanese Islands are also well known for their wealth of edible fish. All fish depend for their existence upon the presence of vegetable and animal organisms in the sea, upon which they feed (although many species obtain their food by devouring smaller species), and it is in the shallow seas that these organisms flourish to best advantage.

Fisheries of the World.—The herring is the most important fish caught about the British Isles, and the number of people engaged in this branch of the fishing industry probably exceeds all the rest together. The chief towns engaged in the industry are Youghal, Kinsale, Clifden, Stornoway, Wick, Peterhead, Aberdeen, Grimsby, Yarmouth, and Lowestoft. Other fish caught off the British Isles include hake, turbot, sole, lobster, mackerel, whiting, haddock, and halibut. Off the coast of Iceland and the Newfoundland Banks are the chief cod-fishing centres in the world.

In the Mediterranean the most important fishing centres lie off the Italian and Sicilian coasts. These districts are noted for their tunny, sardine, and pilchard fisheries. The Gulf of Otranto has important oyster-beds. This shell-fish thrives best in estuaries where the water is muddy and shallow. Oysters are accordingly obtained at the mouth of the Thames, off the estuarine islands of the Dutch coast, and along the east coast of North America, especially in Chesapeake Bay. Sponges, which are marine animals, are to be obtained in the Levant. Coral and pearls are also procured from the sea in warm regions. The Gulf of Manaar is the richest pearl-fishing centre in the world, the pearls being extracted from shell-fish which are brought to the surface by native divers. The whale (which is a mammal, not a fish) provides us with excellent oil, which is procured from its blubber, and also with whalebone, which is taken from its upper jaw. For whaling in northern regions, the whalers start from the northerly ports of Dundee, Aberdeen, and Lerwick. The sperm-whale is found in the South Atlantic and especially in the South Pacific. There are many permanent whaling-stations, whence launches go out in pursuit of whale of various species, round the coasts of South Africa, Australia, and New Zealand (see pp. 499-503).

EXERCISES

1. Describe the following landscape and state what have been the most important agents in shaping it: a fiord coast. (Oxf. and Camb. Lower Cert.)
2. Why is Argyllshire often described as a "half-drowned country"?
3. Give some account of the features which would induce you to believe that a tract of country had undergone upheaval in recent times, and mention a case of the occurrence of such an upward movement. (Camb. Sen. Loc.)
4. What are the present effective forces which cause gradual or sudden changes in the contour of the land? Illustrate your answer by examples.
5. Give instances, in different parts of the world, of large districts of land which lie below sea-level. Explain in each instance what is the nature of the barrier that prevents these districts from being flooded by the sea. (Civil Service.)
6. The coast-line of many countries is in some parts much indented and in others unbroken. How does the country inland from the one kind of coast differ from that inland from the other? Give examples. (Oxf. Prel. Loc.)
7. Describe, by reference to examples, the characteristic features of a coast-line which has undergone considerable subsidence. Quote examples from Great Britain and the southern hemisphere. (Oxf. and Camb. Sch. Cert.)
8. Describe a sea beach where new land is being formed by the sea. (Camb. Jun. Loc.)
9. If the sea-level rose 600 feet all the lowland parts

of Great Britain would be submerged. Describe shortly, or show by a sketch, what the map of Great Britain would look like. (Oxf. Jun. Loc.)

10. What evidence is there that certain coasts are rising and others sinking? (Civil Service.)
11. Describe and account for the difference in the outlines of the coasts on the east and the west of Scotland. (Oxf. and Camb. Lower Cert.)

PART IV

THE LITHOSPHERE

CHAPTER XXIII

Land Forms

Main Features.—If the earth could be deprived of all its hydrosphere just long enough for observations to be taken of the surface remaining, the result would probably be surprising. The Alps of Switzerland, the Himalayas of Asia, the Rockies and the Andes of America, would no longer constitute the most striking features. What we call continents would, instead, stand out as huge uplifted masses, between which would be the enormous depressions that at present contain the oceans. Hence the mountains and the plateaux are not really the chief of the world-features, but (when you consider the world in mass) quite secondary. The *primary* topographical features of the earth, then, are the continental masses. All separable features of these, such as plains, plateaux, mountain systems, and basins, are *secondary* topographical features. Smaller features such as individual peaks, capes, cliffs, valleys, which form parts of secondary features, are the minor topographical features. A **geographical unit** is usually a secondary topographical feature, since it embraces an area or region over which similar conditions of rainfall, temperature, vegetation, and agricultural or industrial possibilities prevail. Where the secondary topographical feature is of extraordinary extent, as for example the basin of the Mississippi, it becomes necessary to divide it into two or more geographical units, such as the Ohio Valley, the Lower Mississippi, the Upper Mississippi, and so forth.

The Two Acting Forces.—Topographical features owe their existence to the action of two forces, one internal, to which are due all movements of uplifting or subsidence, the other external, to which are due all the wasting, carving, and other works of denudation. The first agency builds up secondary features for the second agency to act upon and carve into minor features. A plateau might be the outcome of an uplift of the sea-floor (internal agency); glaciers, running water, frost and sunshine, might dissect this plateau into a group of isolated hills (external agency). Therefore, we may say that the internal agency is chiefly movement and is constructive, while the external agency is chiefly denudation and is destructive; the former tends to produce elevations and depressions, the latter to reduce everything to a common level.

Denudation.—Denudation may be either marginal or superficial: the former is the work of tides and waves on the coasts of the land; the latter, sometimes called sub-aerial, is the work of rain, running water, frost, ice, and air on the surface rocks of the crust. Marginal denudation works at the edges of the land masses just as a mouse eats its way laterally into the mass of a slice of bread and butter; sub-aerial denudation works on the top of the land masses just as a cat licks away the butter from the top of the bread.* The piecemeal breaking-up of the general surface of the land by the oxygen of the atmosphere, by alternations of heat and cold, by percolating water, and by decaying vegetation, is called weathering, and is dealt with in the chapter on that subject. Weathering prepares for transportation, but does not transport. Winds, waves, glaciers, and rivers do the work both of erosion and of transportation. By the various forces of denudation plateaux are carved out into valleys and hills, valleys are deepened and widened, and mountains are made more rugged and precipitous. The coal-measures of northern England once extended right across the country, forming a great arch over the fold of the Pennines. The top of this arch, including the coal-seams, has been worn away by wind, rain, and weather, the older rocks along the axis of the arch have been exposed, and the seams now appear only on the two flanks of the arch, on the east in the Yorkshire coal-field, and on the west in the South Lancashire coal-field. The Weald between the North and the South Downs is a valley that has been worn away from what was once a chalk-covered dome (see fig. 83).

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* The work of tides, waves, winds, glaciers, and rivers is dealt with in their respective chapters.

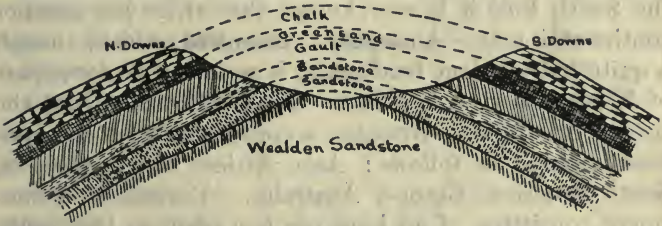

FIG. 83.—The sandstone watershed in the middle of the Weald is not shown.

Primary Features.—The continental protuberances from the crust are conveniently taken in the following way. First, we divide the world into two parts—the one containing what was tolerably well known prior to the famous voyage of Christopher Columbus in 1492, the other comprising what became known as the result of that voyage; the former we call the **Old World,** the latter the **New World.** In the Old World the continental masses are **Eurasia,** consisting of the two quasi-continents Europe and Asia, **Africa,** and **Australia**; in the New World are **North America** and **South America,** really one mass, but so nipped at the Isthmus of Panama that it may quite well be considered as two separate masses. Round the South Pole it is now known that there lies another continental mass—**Antarctica.** **Greenland,** which, though a quite independent land mass, is reckoned to form part of North America, is a large island about one-third the size of Australia. Arranged according to size, the continents stand as follows: Asia, Africa, North America, South America, Europe, Australia. Eurasia is a continent consisting of an immense low plain in the north, somewhat faintly divided by the Urals, and fringed by a line of highlands which sweeps round from the extreme south-west to the extreme north-east (*i.e.* from Spain to the Bering Sea). Africa is a tableland with a fringe of coastal plain. North and South America have mountain ranges in the east and in the west with central plains between. Australia has highland in the west, a mountainous east, with lower land in between. If all the high land of a continent were levelled down and the valleys filled up till the continental mass became quite flat, the height of the then level surface above the sea would be the average height or the mean level of the continent. The mean level of Asia would be about 3,000 feet, of Africa, North America, and South America, about 2,000 feet, of Europe and Australia about 1,000 feet. The true coastal shape of the continental masses is not that shown by the coast-line at sea-level. The outer edge of these masses is the edge of the continental shelf (see p. 324), and it is this which defines the true coastal outline of a continental mass. Any land rising up on a continent to a height of over 5,000 feet above sea-level may be termed the continental crest, all land dipping from 5,000 feet to 500 feet may be spoken of as the continental slopes, and any part not reaching 500 feet may be regarded as a plain.

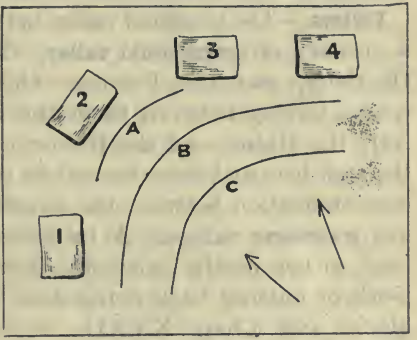

FIG. 84.

Secondary Features.—Syncline and Anticline.—Of secondary features the first in importance is undoubtedly the **mountain chains** or **mountain systems.** Each continent has its own system of elevated lands, and in almost every case they are primarily due to the crumpling of the crust by lateral pressure. Single peaks, or groups of peaks, are usually due either to the dissection of a plateau or to volcanic action. To understand the formation of a system of *folded* mountains, perform the following simple experiment: Cover a table with a thick baize cloth, and upon the cloth lay four heavy volumes, *e.g.* early editions of the *Encyclopædia Britannica*, as shown in the diagram (fig. 84). Vol. I represents the Auvergne Plateau of France, Vol. II the Vosges Mountains, Vol. III the Black

Forest Mountains, and Vol. IV the Bohemian Plateau. All these are igneous * protrusions, and act as gigantic posts sunk through the crust to the centrosphere. Now push the tablecloth upon the table towards the volumes, when three folds or creases will appear along the lines marked *A*, *B*, and *C*. Fold *A* represents the Jura fold, *B* and *C* the parallel folds of the French, Swiss, and Austrian Alps. The trough of a fold is called a **syncline,** the arch an **anticline.** † With a double or treble fold there must be both anticlines and synclines.

Valleys.—The synclinal valley between two folds is called a primary or **longitudinal valley.** The Juras, the Bernese Oberland, and the Pennine Alps are three anticlinal ridges, having between them the synclinal valleys of the Aar, the Rhine, and the Rhone. The anticlines are cut through here and there by valleys (not synclines) affording communication between the longitudinal valleys. These are **transverse valleys.** A transverse valley may be cut back either partly or wholly through the anticline, the work of cutting back being done by either a river or a glacier (see Chap. XXXI). It is this combination of longitudinal and transverse valleys which so greatly adds to the commercial value of the Alpine passes, and the Alps may be contrasted in this respect with the Pyrenees, the peaks of which are much lower, but the passes much more inaccessible. Sometimes there is a single bend or fold without a trough. Such a simple anticline occurs upon the Colorado plateau of Utah and Arizona. The plateau has an average height of about 7,500 feet, and breaks off suddenly with the long line of cliffs known as the Mogollon escarpment. The strata of the plateau are in North-east Utah bent into the one single fold of the Uintah Ridge, which averages 13,500 feet, or 6,000 feet above the average of the plateau. Through the ridge the Green River has cut a transverse gorge. The Alps, the Himalayas, the Rockies, and the Andes are all chains of folded mountains, as also are the Atlas Mountains of North Africa, the Sierra Nevada of South Spain, the Apennines, Carpathians, Balkans, and the Caucasus.

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* Made by or through the agency of fire.

† The difficulty of remembering which is the anticline and which the syncline may be overcome by noting that A stands for arch as well as for anticline.

Plains and Plateaux.—The other important secondary features are **plains** and **plateaux.** Both these have comparatively level surfaces, and the distinction between them is chiefly one of elevation, plateaux being plains at some considerable height either above sea-level or above the level of the surrounding country. Their modes of origin may be the same; both may be formed by uplift, but the plateau would be more uplifted than the plain. In some cases the uplift of a plateau takes place so slowly and gradually that the strata remain almost horizontal, and instead of slopes on the outskirts of the rising region faults * occur, so that ultimately the plateau is bordered by terraces that lead downwards to the surrounding low land. Much of the African plateau which lies south of the equator has this formation, although the scarps of the terraces have been worn back and do not now indicate the position of the great fractures. This terrace formation bordering the African plateau has the effect not only of hampering railway development by necessitating excessively steep gradients from the coast to the interior, but also of hindering the complete navigation of the great African rivers because of the waterfalls that are bound to occur on the lower courses, though the upper courses are quite navigable. The Congo, for instance, is navigable for 1,000 miles from Stanley Pool to Stanley Falls, but the falls of the lower river prevent communication with the sea, and a railway has had to be constructed to overcome this obstacle. The southern buttress of this plateau in Cape Colony is a folded range pressed against the plateau. The Deccan of India is a plateau of similar formation, the terraces of the Western Ghats being specially well marked. An uplifted plain with the strata almost horizontal is of a formation similar to the uplifted plateau, but as the uplifting has not proceeded far above sea-level there is no faulting on the outskirts and consequently no terracing. Western Siberia is a plain of this kind. This plain was once below the sea-level, and the Caspian and the Aral are the last remains of the shut-off and pent-up sea-waters. Coastal plains, due to deposition followed by uplifting, are not bound to enclose portions of the sea-waters, the plain of East Anglia being a case in point. Sometimes marine denudation occurs before the uplifting, as was the case with the small area in Pembrokeshire south of Milford Haven. The plain of Belgium and North-east France lying west of the Ardennes plateau was once a region of folded and faulted mountains very much crumpled and broken. The whole of this region is now worn so flat that scarcely a trace of the high land remains. The cross-faulting that must have been common easily accounts for the sudden disappearance and unexpected reappearance of the coal-seams of this region. Such a plain might be called a plain of denudation. Drainage basins may be either plains or plateaux ; the Great Basin of the Rockies is a plateau basin, those of the Ganges and the Mississippi are plain basins. Where rivers cut deep and wide valleys through a plateau, ridges and isolated peaks are the result. A plateau dissected in this way presents a highland region of a very irregular and rugged character. The mountains of the English Lake District are the remains of a dissected plateau; in fact, the characteristic feature of British mountains is that they have been dissected into their present group-formation from an ancient level-topped plateau. The truth of this is specially evident in the Highlands of Scotland, where the residual ridges and peaks reach approximately the same level. The central Lowlands of Scotland is a rift-valley between two faults, one stretching from the Firth of Clyde to Stonehaven, the other from Girvan to Dunbar. The termination of the Highlands along the former fault-line is very clearly defined; for, seen from the plain of the rift-valley, the front has a distinctly wall-like appearance. Another fault right across this northern plateau formed the rift of Glenmore, now utilised by the Caledonian Canal. Scandinavia is also a dissected plateau. The Balkan Peninsula is made up of two systems of folded mountains, between which is a high, rugged, dissected plateau. The Iberian peninsula is a curious formation. Most of the interior consists of a high rugged plateau called the Meseta, varying from 2,000 to 5,000 feet in height, above the level of which rise several saw-toothed ridges called **sierras.** North of the Meseta lie the parallel folds of the Pyrenees, and on the south are the folded ranges of the Sierra Nevada, detached portions of the latter folds reappearing in the Mediterranean as the Balearic Islands.

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* Sometimes in the process of uplifting, the crust mounts too high to remain stable. A crack or split then occurs in the crust, and on one side of the crack the crust slips down to regain its equilibrium. The slipping down is called subsidence, and the displacement of strata is called a fault.

Crust-blocks.—Besides the folded mountain-systems, the dissected plateaux or residual mountains, and isolated volcanic peaks, there are isolated mountains that owe their origin to a network of cross-faulting. Intersecting fracture lines form irregular quadrilateral and polygonal figures. If one of these remains *in situ,* while those surrounding suffer subsidence or depression, the surviving rock-mass becomes what is known as a **crust-block** or an **earth-block.** The Peninsula of Korea is an example of such an earth-block. If, however, the outstanding block is the result of the denudation of the surrounding parts, it is called a **butte** or a **mesa.*** Table Mountain, which overlooks Cape Town in South Africa, is such a hill, and there are many other examples of the same formation in other parts of the same country, all rimmed round by unscaleable cliffs rising out of long slopes of weathered rock-waste, which are called "screes" or *talus* slopes. Earth-blocks may be said to be the result of circumdepression, buttes of circumdenudation.

Various Kinds of Plains.—In rainless regions, plateaux generally remain level, and it is only their borders that become dissected, as is the case in Western Australia. Many plains in different parts of the world have special characteristics and special names. Round the Aral Sea and stretching northward into Asia lie loamy plains frozen in winter, green with rich grass in spring, and scorched and withered in summer. These are called **steppes.** They are the home of nomads or wanderers, who are compelled to lead their kind of life in order to procure fresh pasture for their flocks. The northern wastes of Eurasia, with nearly barren frozen soil, are called **tundras,** which in the summer-time thaw on the surface and carry a growth of stunted shrubs, thin grass, and a profusion of bright-coloured flowers. In North America the same kind of frozen plain is called the **Barren**

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* Pronounce *bewt* and *maysa.*

Lands. Bare and sandy wastes, mostly on or near the tropics, incapable of habitation, are called **deserts.** They are all regions of great heat (and also, in the Central Asian deserts, of great cold) with next to no rainfall. Hence the plants that inhabit them are such as have thick, fleshy leaves like the cactus, or those that can store quantities of water, like the gourd so common on the Kalahari Desert. The grassy plains of the Plate River in South America are called **pampas,** those of the Orinoco, **llanos,** and the densely wooded plains of the Amazon, **selvas.** These last, a gloomy forest tract, are almost impenetrable save by water.

Minor Features.—Chief among the minor features is the **peninsula.*** A peninsula is a land mass that by being severed on one side across its attachment to the main mass would become an island, or, simply, a land mass that is almost an island. Great Britain, being entirely surrounded by the sea, is an island; but Scotland, or England, or Wales, taken separately may be considered as peninsulas. The whole of Europe west of a line drawn from Danzig to Odessa is a peninsula, and branching from it on either side are the secondary peninsulas of the Balkan States (with the Morea as a tertiary adjunct), Italy, Iberia, Brittany, and Denmark. In North Europe Scandinavia with Lapland forms a hammer-head peninsula. The east and south of Asia are fringed with peninsulas, the chief of which are the Malay peninsula and the plateau peninsulas of Arabia and the Deccan. The whole of Africa, of North America, and of South America are by nature peninsulas, but artificially islands. North America has several secondary peninsulas, such as Labrador, Nova Scotia, Florida, and California. All peninsulas are not joined to the mainland by an **isthmus**:

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* *Peninsular* is an adjective, cf. *insular.*

the Deccan, for example, is joined by a broad base to the continental line ; the Morea, however, is joined by the true narrow-necked Isthmus of Corinth to its parent peninsula, and the Crimea is similarly joined to the Russian mainland by the Isthmus of Perekop. Other well-defined isthmuses are those of Suez and Panama, both cut through by canals.

Islands are of two kinds : (1) those rising from the continental shelf are called **continental**, (2) those rising from the floor of the ocean abyss are called **oceanic.** Continental islands are often a line or festoon of peaks of submerged mountain ranges, such as the Ionian Islands on the west of the Balkan peninsula, the Sunda Islands of the East Indies, and the Greater and Lesser Antilles of the West Indies. They are often also peaks of a submerged, dissected plateau, as in the case of the Cyclades of the Ægean Sea (such a grouping of islands being called an **archipelago**) ; or single peaks such as the Isle of Man, which is a detached fragment of the Lake District; or, again, they are remains of continental areas whose surroundings or intervening parts have foundered, such as the British Isles, Madagascar, Greenland, and the many large islands north of Canada ; and, lastly, they may be mere stacks of hard rock that have so far resisted the attacks of the waves, such as Heligoland, the Bass Rock in the Firth of Forth, or Ailsa Craig off the south-west coast of Scotland. Oceanic islands have never been joined to a continent, but have been built up from the ocean-floor either by coral polyps or by volcanoes. (For fuller details of coral formations, see Chap. XXX.) The islands of the Central Pacific are oceanic, and they contain none of the typical rocks of the continental masses, such as granite and sandstone and clay. Oceanic islands generally have plants and animals peculiar to themselves, while continental islands contain the faunal and floral features of the neighbouring continent. New Zealand is, for instance, an oceanic island with peculiar plants and animals. Many oceanic islands in the Atlantic are volcanic, such as Teneriffe, the Azores, and the Cape Verde Islands.

Types of Coast-line.—Capes (called also points, forelands, nesses, heads, and bills) are coastal corners, coastal tongues, or miniature peninsulas. A bold, high, and outstanding cape is called a promontory. A good study of capes may be made from the coasts of our own islands; for we have three quite distinct types of coast-line, giving rise to three distinct types of capes. These types of coast-line may be called the serrated, the concave, and the convex.

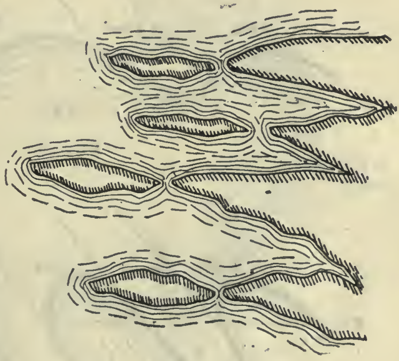

Fig. 85.

Fig. 85 shows the serrated type found on the west coasts, especially on the west coast of Scotland, and in its most pronounced form on the south-west coast of Ireland. The serrations are *not* due to the erosion of soft rock, but to the subsidence of valleys. The concave type is found well shown on the south coast of England, where each projecting point (fig. 86) is a hard band of rock jutting out into the sea. There is a limit beyond which the gulf of sea-water does not penetrate; for the inner parts beyond the line *XY* (fig. 87) are sheltered from the violent action of waves, and the consequent tendency to deposition gives the fixed concave character to the coast. The convex type is well shown on the east coast of Great Britain, but best of all in England. This form (fig. 88) is due to a growth of coast caused by a tidal current flowing southwards along the east coast of Great Britain (or similarly along the west coast of Denmark and Germany). This current tends to carry everything southward, and so brings down sand which blocks the mouths of the rivers and deflects them (*e.g.* the Alde, the Yare, etc.) so that one of them, instead of entering the sea at *X* (fig. 89), enters at *Y*. Whatever may have been the original

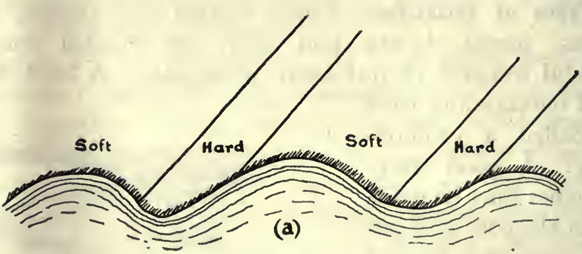

Fig. 86.

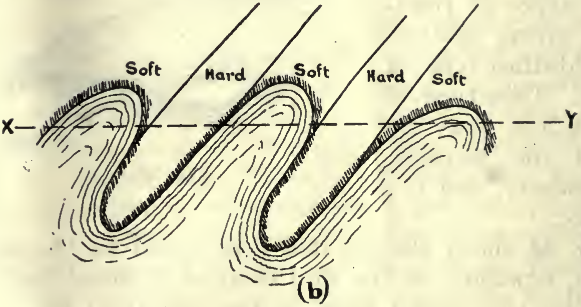

Fig. 87.

shape of the east coast, this south-flowing current would have made it convex to the sea in course of time by building bars across the bays. The current flowing along the German coast is a wind-current, not a tidal current. Long, capeless coast-lines sometimes occur as the result

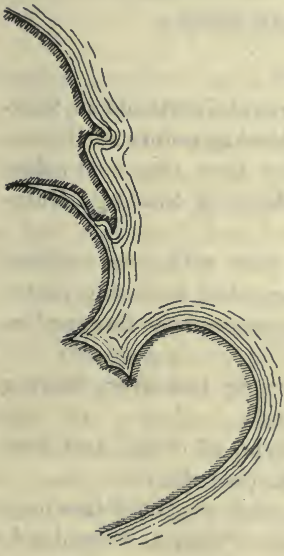

FIG. 88.

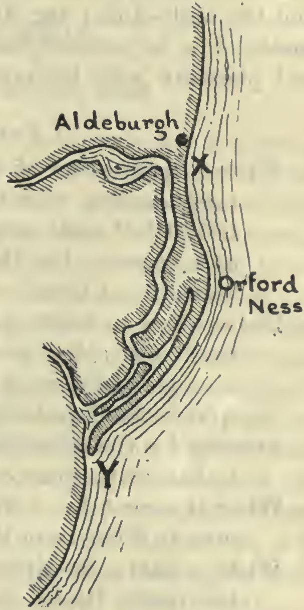

FIG. 89.

of the sinking of a former sea-slope along a nearly straight fault-line, as is the case in South-west Africa and West India, and sometimes where mountain ranges lie parallel with the shore, as is the case along the west coast of the United States and the coasts of Peru and North Chile. If a river has cut its way back (see p. 428) through such a coastal mountain range, it will flow in a narrow gorge through the mountains, but will often have a good harbour in one of the valleys on the other side of the mountains. A good example is the Bay of San Francisco which is entered through the Golden Gate. The Pacific Ocean has on the whole the type of coast due to the parallel mountains and the fault-cliffs; the Atlantic has the more irregular coasts due to submergence of butt-ending mountains and plateaux with intervening low lands.

EXERCISES

1. Write a description of the Central Lowlands of Scotland, dealing with the following points: climate, fertility of soil, accessibility from sea, coal-fields, and account for the position of Stirling, Dumbarton, and Perth.
2. Plains often coincide in great part with river-valleys. State with what river-valleys the following plains coincide and give six further examples—Languedoc, Andalusia, Lombardy.
3. Account for the directions taken by the rivers flowing to the south coast of Ireland.
4. What is meant by a Pacific type of coast, and how does it differ from the Atlantic type?
5. Write a short description of each of the following: the Great Basin, the Pamir Plateau, Greenland, the Andes.
6. Compare the general build of Eurasia with that of the Americas, and of Africa with that of Australia.
7. What land is there in the southern hemisphere? (Oxf. Jun. Loc.)
8. What is meant by classing islands as "continental," "volcanic," and "coral"? Explain the difference. (Army Entrance.)

CHAPTER XXIV

The Rocks of the Earth's Crust

Rock.—By the " crust " of the earth we mean the outer solid part which by observation or reasoning may be considered as *known* to some extent. Direct observations made in wells, mine-shafts, cuttings, cliffs, ravines, cañons, etc., carry knowledge of the crust no farther than a few thousand feet from the surface. Reasoning by inference may carry our knowledge farther, perhaps nearly forty miles from the surface, but even this knowledge embraces no more than one-hundredth of the distance from the surface to the centre. Any portion of natural substance forming part of this crust is, to a geologist, **rock.** In popular language " rock " signifies masses of hard stone, and does not include loose soil, a distinction of much convenience ; for allowing the distinction, we can speak of the solid rock of the crust being covered with a softer, looser material called **soil,** which is nothing but the result of the decomposition of exposed rock-surface. In composition rock is commonly an aggregate of different mineral substances, not combined in any constant way, but varying in detail in different localities. Thus the name " mineral " generally signifies something simpler than a rock. Minerals have a definite chemical composition and definite physical properties, but the aggregate of minerals in a composite " rock " has no constant composition. If from any mineral there can be extracted one of the useful metals, such a mineral is called an **ore.** Those metals, such as gold, silver, and platinum (precious metals), and some others, when they are found pure and have not to be extracted from an ore, are called **native.**

Common Rock-forming Minerals.*—The most abundant mineral in the earth's crust is **silica,** a compound of silicon and oxygen. It occurs in many forms, from the bright, clear, transparent, hexagonal crystals of quartz or rock-crystal to the dull-looking, dark-coloured flint. Other well-known forms of silica are purple quartz or amethyst, smoky quartz, opal, and agate. When silica combines with certain metallic substances it forms compounds known as **silicates,** the commonest of which are the *felspars.* Typical felspars are the pink crystals that give the characteristic colour to red granite, or the nearly white crystals of grey granite. Another well-known silicate is **mica,** easily recognised as dark specks in common granites. There are many forms of mica, but they all agree in being sufficiently soft to be scratched by the finger-nail, and in being splittable into thin flexible plates or leaves (*laminæ*). One form of mica called muscovite (often wrongly called talc) splits into large, thin, transparent sheets often used in the place of glass. Another important mineral is the compound of carbon, oxygen, and calcium known as **calcium carbonate.** This exists in many forms, the commonest of which are **chalk, limestone,** statuary **marble,** and **calcite.** Crystals of calcite may be easily mistaken by the young student for crystals of quartz. Either of two tests, however, will make the difference quite clear. Upon your crystal place a drop of hydrochloric acid: if effervescence takes place, the crystal is calcite; if not, it may be quartz. Or, scratch your crystal with the point of your penknife: if the scratching is easy, the crystal is calcite; if the knife will not scratch, the crystal may be quartz. The pure transparent form of calcite is called Iceland spar. If you can obtain a crystal of Iceland spar, place it upon a page of a printed book, and notice what happens to the print beneath it. In marble the small crystals of calcium carbonate are matted together, as you may see by examining a specimen with a magnifying-glass. Limestone and chalk are forms too common to need description. A compound of calcium carbonate and magnesium carbonate (the chief source of the drugs containing magnesium) forms the magnesian limestone called dolomite, of which the Houses of Parliament are built. This rock-forming mineral, which is found in large quantities in the Karst region in Austria, was first discovered in 1794 by the French geologist Dolomieu after whom it is named. When pure, it is perfectly white in appearance, resembling statuary marble, and the dazzling whiteness of the so-called "spiked dolomites" of the Carnic Alps provides a novel and a glorious spectacle. Gypsum, a hydrous sulphate of calcium, easily cuts with a knife, but does not effervesce with an acid. A common name of gypsum is plaster-spar. **Carbon,** as a mineral, is found pure in the form of diamonds, and nearly pure in the form of plumbago, sometimes called graphite or black-lead. The abundant deposits of graphite in Bavaria have led to the establishment there of the lead-pencil industry. Coal, which has its origin in former plant life, and coral, which has its origin in former animal life, are *organic* rock-materials.

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* The student should collect or inspect specimens of the minerals mentioned. Mere reading about them is very little good. The "M and L" case of specimens to illustrate this chapter can be obtained from Mr. F. H. Butler, the Natural History Agency, 158, Brompton Road, London, S.W. Price 10*s.* 6*d.*

First Classification.—In the beginning the whole crust of the earth solidified through gaseous and liquid stages. This first solid crust, consisting of rock that had passed through the molten state, is called **igneous rock.** This original crust of the earth was full of wide and deep hollows into which, as time went on, the worn-down dust and fragments of the more elevated parts of the igneous rocks made their way. All such layers which owe their origin to the destruction of the igneous rocks are called **sedimentary rocks.** In fig. 90 it will be seen how the sedimentary rocks (*S*) always lie on a foundation of igneous rocks, and how here and there portions of igneous rock (*P*) protrude beyond the layers of sedimentary.

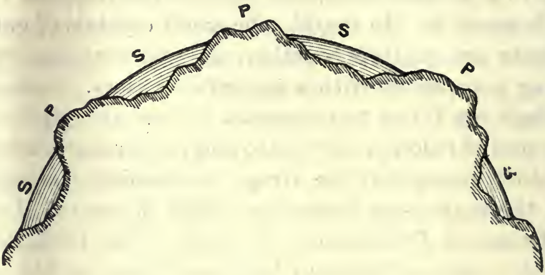

Fig. 90.

Further Classification.—Sedimentary rocks—that is, rocks which have been reduced to sediment by erosive water-power, and have been carried away by water to be deposited in another place—are sometimes called **aqueous,** because they owe their deposition to water. It is in this sort of rock (called therefore also fossiliferous) that organic remains or fossils are found. In the original crust of the earth, or in volcanic material, traces of life could not be expected to exist.

Igneous rock, as might be expected from its origin, commonly occurs in an unstratified condition; and it is also often found in a crystalline condition. If the igneous rock solidified in the depths of the earth, each mineral crystallising out slowly and separately, it is called **plutonic**; granite is the best known of this class. If the igneous rock is the result of an ejection of lava on the earth's surface, it is called **volcanic.** Thus the term "volcanic" is distinguished from "plutonic," in that the former designates igneous rocks of superficial formation, while the latter is applied to rocks formed under conditions of depth and pressure. Some lavas having the same mineral composition as granite, and others that solidify as black glass, are called obsidian. Glassy lava that solidifies full of air-bubbles is called pumice. Stratified rocks may be first classified according to the material of which they are composed, and again according to their age. **Arenaceous** or sandy rocks consist of small fragments of mineral, mostly quartz, broken up into fine particles and cemented together by various substances, such as iron oxide or carbonate of lime. **Argillaceous** or clayey rock consists of finely pulverized rock-forming minerals or the products of their alteration. If the argillaceous rock is not fissile it is called clay or mudstone; if fissile and not very hard, shale; if fissile and very hard, slate. If a rock contains calcite in any form, it is called **calcareous.** The special characteristic of such rock, *e.g.* chalk, common limestone, and statuary marble, is that it effervesces under acid. Stratified rocks, containing carbon-bearing or coaly matter, owing to the incorporation of plant remains, are called **carbonaceous.** If soft and formed of compacted and little altered plant remains, the rock is called lignite *; if hard and still more altered, approaching pure carbon in composition, bituminous coal; if very hard and much altered, anthracite. At first all stratified rocks were approximately horizontal; but so much tilting, folding, bending, crumpling, and other forms of distortion of the crust have taken place since their deposition, that a nearly horizontal bed is now the exception and not the rule. The direction down the slope of a bed of stratified rock is the **dip**; the direction along the slope at right angles to the dip is the **strike**; the line along which the bed comes up at the surface is the **outcrop**; and a line of break in the bed is a **fault.** Dip, outcrop, and strike may be illustrated with a few books placed as in fig. 91. Sometimes the strata of the rocks are broken through by masses of igneous rock in a molten state from the interior. These masses by their intrusion harden by pressure, or bake by heat, or chemically alter the sedimentary rocks into which they have entered. Such altered rocks are said to have been metamorphosed (*i.e.* changed) and are called **metamorphic.**

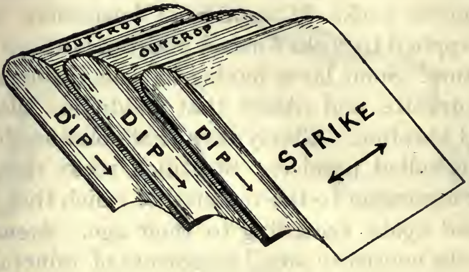

FIG. 91.

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* Peat (though it can hardly be called "rock") may be regarded as the first stage in the formation of coal out of vegetable remains.

Chronological Classification of Stratified Rocks.—The history of pre-historic races of mankind can be studied from the implements they used. The earliest men used rough stone implements and weapons, later men used better stone weapons, later still bronze to some extent took the place of stone, and so on. A clue to the history of the sedimentary rocks is afforded by the entombed remains of animals and plants that lived during the periods when the different strata were being laid down. These animal and plant remains are called **fossils.** The very oldest of the stratified rocks have been mostly metamorphosed and contain no fossils. Some of these rocks were probably formed in that stage of the history of the world when life was non-existent. They are called **Azoic** (or without life). To this stage or group belong certain slates, and some of the banded rocks called gneiss. Following these formations came an epoch named the **Palæozoic,** because all fossils in the strata laid down during that epoch are old forms of life, such as invertebrates and fishes. Later came the epoch in which reptiles abounded and birds began to appear. This is the **Mesozoic** epoch. Lastly, there comes our own epoch, called **Cainozoic.** Though new forms of life appear in each successive epoch, certain older forms still persist. The full chronology is set out in the table on next page.

Stratigraphical tables should always be read from the bottom upwards. Each formation represents an immense period of time, probably millions of years; but indeed the best way to think of the formation-periods is to leave out altogether the idea of years; and it must also be borne in mind that the periods are not necessarily of anything like equal length. They are best regarded as stages in the history of the earth. Thus, the Jurassic formation-period represents the stage when the only mammals

Epoch.	Formation.	Life forms as shown by fossils.	Examples of rocks.
Cainozoic or late life [Tertiary strata]	Quaternary	Glacial period	Boulder clay, sands, gravels, and alluvial soil
	Tertiary *	Mammals develop in great variety. Man appears	Sands, clays, and crag
Mesozoic or middle life [Secondary strata]	Cretaceous	Higher mammals begin; land plants and insects develop	Chalk, marl
	Oolitic or Jurassic	Reptiles and amphibia predominate; birds appear	Limestones, fuller's earth
	Triassic	Reptiles in great variety; low forms of mammals appear	New red sandstone and gypsum
Palæozoic or early life [Primary strata]	Permian	Reptiles appear	New red sandstone and marl
	Carboniferous	Land plants; amphibians	Coal and millstone grit
	Devonian	Fishes abundant	Old red sandstone
	Silurian	Invertebrates still prevail	Flagstones and slates
	Cambrian	Nothing beyond invertebrates	Slates and grits
	Archæan	Obscure traces	Schists, and crystalline rocks
Azoic or no life	Metamorphic	None	Gneiss and slate (*All igneous rocks consolidated from fusion are necessarily azoic*)

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* In 1912 in the tertiary beds at Piltdown Common in Sussex was found a skull, which is the earliest indication of human life yet disentombed from any stratum of the earth's crust. It belongs to an earlier period even than the jaw found at Heidelberg in 1907. The characteristics of the Piltdown skull are small brain-capacity, heavy under-jaw, and large powerful teeth. A model of the skull may be seen in the Natural History Museum, South Kensington.

as yet known were of a low type, and when the predominating forms of animal life were those of huge amphibia and reptilian monsters.

The Rocks of the British Isles.—Primary Strata.—When we say that the proportion of igneous rock in the British Isles is very small, it must be understood to mean that compared with the total surface area of the islands the *outcrop* of igneous rock is very small. The basaltic plain in North-east Ireland* is volcanic in origin, and similar rocks appear in the islands of Mull, Staffa, Iona, and Skye, and in odd detached places on the Lowland plain. Under these volcanic outpourings in many places lies a foundation of crystalline schists of Archæan formation. The Archæan rocks, the oldest rocks of the British Isles, are mainly represented north of a line drawn from Stonehaven in Scotland to Sligo in Ireland. Small exposures of Archæan rocks occur in England where later rocks that once covered them have been worn away, *e.g.* in Cornwall, in the Malvern Hills, and near Leicester. Cambrian and Silurian slates and grits cover most of the southern uplands of Scotland, the south-east of Ireland,† much of the Lake District of Westmorland, a portion of North-east Ireland south of the basaltic plateau, and all Wales except the south-east corner. The Old Red Sandstone outcrops in the south-west corner of Ireland, in South-east Wales, the coastal regions of Moray Firth, the whole of Caithness, and the northern parts of the central Lowlands of Scotland.

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* The Giant's Causeway is a small local portion of this basaltic plateau.

† In the east and south-east of Ireland is found granite of even greater hardness and durability than the grey granite of Aberdeen. Large quantities of this stone in the form of blocks have been shipped from Kingstown to Australia for the building of piers.

Under the Old Red Sandstone beds lie the Silurian rocks, and later in succession are shales and limestone that underlie the coal-seams, *i.e.* the carboniferous limestone. This carboniferous limestone is now well seen in the southern parts of the central Lowlands of Scotland, down to the Pennine backbone of England, over the whole of central Ireland, and along the coast of South Wales. In the above formation is found the coal that gives the formation its name. In Ireland the upper coal-bearing beds have been worn away. In Scotland the carboniferous rocks bear such rich stores of coal, iron ore, and oil shale, that the central valley is the most prosperous and important part of Scotland. In England the sequence of formations may be seen exposed upon the flanks of the tiny plateau of the Forest of Dean. On all sides you may climb up from Silurian slates to Devonian sandstone, thence from the carboniferous limestone to the cap of shales and coal-seams. The disappearance of the upper coal-beds from the Pennines has already been mentioned (see p. 331).

Secondary Strata.—Resting upon the Permian and other rocks are the Triassic beds of red sandstone, marl, and gypsum. This formation, which occurs over the midland plain between the Pennines and the Welsh hills, and on the east flank of the Pennines up to the River Wear, contains beds of common salt. From the mouth of the Tees to the mouth of the Exe runs an irregular band of Jurassic deposits, which dip eastward and strike in the direction of the outcrop, and also divide England into two distinct regions. The outcrop of these beds is called the **Oolitic escarpment,** and is called by various names in different parts, such as North York Moors, Northampton Heights, and Cotswold Hills. East of this escarpment is agricultural England, west of it is industrial England. Above these Oolitic limestones (sometimes called "roe-stone," because of their likeness to the hard roe of a herring) lies the chalk, whose outcrop, lying nearly parallel with the Jurassic, is called the **Cretaceous escarpment.** Between the two escarpments is a belt of loamy clay of high agricultural value called the Jurassic belt. Where the oolitic beds can be got at, good building stone is obtained, as at Portland and at Bath; iron ore is found in Northamptonshire, North Lincolnshire, and the Cleveland Hills of Yorkshire; good clay for brick-making is found all along the Jurassic belt. The cretaceous or chalk escarpment contains the Marlborough Downs, the Chiltern Hills, the East Anglian Heights, the Lincoln Wolds, and the Yorkshire Wolds. The chalk belt is mainly pastoral, but in many parts, where the chalk is marly, it is possible to carry on successfully the manufacture of cement.

Tertiary and Quaternary Strata.—Round the mouth of the Thames and along the coast of Suffolk and Norfolk are Tertiary deposits of sand and clay; and in the Fen District the modern Quaternary alluvial deposits of rich fertile soil have made that region celebrated for the growing of wheat.

EXERCISES

1. What has slate been formed from, and how has it come to be what it is?
2. Where have the grains of sand come from that we find on the sea-shore?
3. How would you distinguish between—(*a*) a diamond and a clear quartz crystal, (*b*) a quartz crystal and a calcite crystal, (*c*) a piece of black marble and a piece of flint?
4. Classify the chief aqueous rocks (*a*) according to their mode of formation (mechanical, chemical, organic),

(*b*) according to their composition (siliceous, argillaceous, calcareous, carbonaceous).

5. Distinguish between a mineral and a rock. Describe three common rocks and explain their origin. (Camb. Jun. Loc.)
6. Of what is coal made? How and in what sort of places was it formed? How is our knowledge of its history and origin obtained?
7. State what is meant by *outcrop* and *fault*, and illustrate your answer with diagrams. (Camb. Sen. Loc.)
8. Give some account of the origin of chalk. (Camb. Jun. Loc.)
9. Name three useful minerals which are generally found as veins filling cracks and fissures in hard rock, and three which are found in layers between deposits of sand and clay. In each case name some locality where the mineral is abundant. (Oxf. and Camb. Sch. Cert.)
10. Discuss carefully the position and the character of the chalk ranges of England east of 1° W., showing their past and present importance. (Lond. Univ. Matric.)

CHAPTER XXV

Weathering

Expansion and Contraction.—Most solids expand when heated and contract when cooled. Take a small brass ball which will just pass through a metal ring when both ball and ring are cold. Heat the ball in the flame of a spirit-lamp, and you will find that it will then not pass through the ring, but will rest upon it. As the ball cools, it contracts, but the ring, being warmed by contact, expands a little. Therefore it will take a few minutes for the ball again to drop through the ring. This experiment shows the principle of the expansion of a solid upon the application of heat, and the subsequent contraction due to loss of heat. All solids do not, however, expand and contract in the same degree. The amount of expansion or contraction depends upon the substance of which the solid is composed and the amount of heat or cold applied. It is said that, owing to the expansion and the filling-up of the interstices between the railway-metals on the line between London and Edinburgh an additional mile of metals is added during the summer. Water does not expand and contract regularly under the application of heat and cold as a solid does. While water is being cooled gradually down to 39·2° F., it contracts normally. At that temperature it commences to expand, and continues to do so until the temperature reaches 32° F.

At this point the water becomes solid ice, and thereafter acts as a solid. But at the point of solidification the water undergoes such expansion that the ice formed occupies $\frac{11}{10}$ of the space previously occupied by the water. Therefore, water not only expands on freezing, but ice, being the solid form of expanded water, is lighter than its equivalent bulk of unexpanded water. This is why ice floats in water with about one-tenth of its bulk above the surface. That water expands on freezing may be easily understood by observing the effect it has upon the pipes through which it flows during the winter. To test the expansive power of water in forming ice, large bomb-shells were filled with water and plugged tightly. These were then placed out in the open during the night in northern Canada, and on inspection on the following morning were found either to be cracked or to have had the plug forced out and ejected a considerable distance away.

Denudation.—The chief effect of the varying climatic changes on the earth's surface is to cause a general denuding and disintegration of the rocks of which it is composed. The natural agencies that assist in this work are air, rain, frost, rivers, glaciers, wind, and the oceans. All of these are destructive in character, and are constantly engaged (although not all in the same regions) in wearing down the rocks of the globe and transporting their particles to places of lower level. For this reason they have been named agents or forces of denudation. Of denudation there are two kinds—(*a*) **chemical** and (*b*) **mechanical.** That is, the destructive agents sometimes exert a force which has a solvent action on the earth's surface; and sometimes they grind it away by brute force, as it were. The agents chiefly engaged in chemical action are air, rain, and wind. Sometimes the word " weathering " is applied to the work done by these agents, and it is in this sense that it is used throughout this chapter.

Air and Rain as Weathering Agents.—Of the several gases which are present in the atmosphere, two have a very powerful effect in denuding the land surface. These are carbon dioxide and oxygen. When rain-water charged with carbon dioxide comes in contact with certain rocks, chemical compounds are produced, and some of the insoluble carbonates are converted into soluble compounds. One of the rocks most easily dissolved by this process is limestone. Oxygen produces a chemical change known as oxidisation on coming into contact with rocks. Insoluble sulphides are in this way converted into soluble sulphates and various mineral constituents of the rock are decomposed. Rain as it falls through the atmosphere absorbs a certain amount of these two gases, and on reaching the ground dissolves some of the mineral substances composing the rocks. A dry atmosphere can therefore have only a slight effect upon surface rocks. On the other hand, a moist atmosphere may have a very considerable effect. Cleopatra's Needle had stood for more than 3,000 years in Egypt—a dry country—with very little change ; but when it was set up on the Thames Embankment in England—a damp country—a single winter so much affected its surface that it had to be coated with a preservative against the weather. In the same way ancient Greek and Roman buildings in southern Europe are almost as magnificent as when they were first built ; but in northern and western Europe, which is moister and colder, and where the annual range of temperature is greater, buildings once neglected soon drop into decay and become crumbling ruins. The Grand Cañon of Colorado illustrates the very small part that the chemical action of the atmosphere can do on its own account. In this exceedingly dry region the river has carved out its bed to a depth of at least 1,000 feet below the surface-level of the surrounding country; its sinuous course is walled in by beds of rock that have withstood for ages all attempts of the dry atmosphere to create any perceptible change. Such a phenomenon as the Colorado cañon would be found only in a dry country; in a damp climate, such as that of the British Isles, the sides of the cañon would never have been perpendicular at all, but would have weathered into the sloping formation of the ordinary river-valley.

Chemical Weathering.—The action of rain upon all rocks is twofold. Together with the mechanical there is also a chemical wearing away. In some cases the chemical action is greater than the mechanical. This may be specially noted in limestone districts, in which the solvent powers of the water have hollowed out huge underground caverns. In other cases the mechanical is greater than the chemical action. This is the case in regions in which the rocks are less soluble, and where frost and thaw are the more powerful weathering agents. A very excellent example of the solvent power of rain is to be observed in the Yorkshire hills, where the chief rock is carboniferous limestone. Here are to be seen huge masses of erratic blocks of hard grit based on a linestone stratum. The grit has resisted the atmospheric agencies, but the great thickness of the limestone layer underneath, which the block has protected from the destructive work of these agents, shows clearly the sculpturing action which has been at work from year to year. The earth-pillars of the Tyrol and those at Fochabers in Elgin are composed of clay and slate which have been in like manner preserved from the weathering process by the caps of stone which surmount them. Again, the " saucer " formation of Ireland is partly due to the solvent power of rain upon the limestone rock of which much of the interior is composed, and partly due to the scooping-out action of glaciers during the later stages of the glacial period (see p. 479). Large hollows so formed have now been filled up with water or vegetable matter. It is believed that the Bog of Allen had its origin in this way. The famous Cheddar caves in Somerset have also been formed through the solvent action of water. In fact, wherever limestone is found, there " swallow holes " or " sink holes " and subterranean channels or caverns caused by the dissolving of the rock are to be met with. In other countries very famous caverns of this kind are the Mammoth Cave of Kentucky and the Jenolan Caves in New South Wales. Some species of animals (and fish) that live in the utter darkness of these caves are blind, but, on the other hand, their powers of hearing and touch are strongly developed (see p. 430).

Weathering by Insolation.—Although certain places situated in the temperate zones have a fairly wide daily and annual range (see p. 136), it is in arid regions like the Sahara Desert that the daily range is greatest. In the British Isles the daily range varies from 30° F. to 40° F.—not a great deal when compared with that of the Sahara, which sometimes reaches 140° F. In high latitudes the greatest extremes of temperature, both for the day and the seasons, are experienced in those places situated at great elevations or in the central parts of the great continental masses. The effects of a wide daily range of temperature are very marked upon the surface rocks, which expand rapidly when subjected to the great heat during the day, and contract equally quickly, as the heat is radiated into the atmosphere during the cool night. In contracting, the inner layers of the bed of rock give off their heat more slowly, and consequently do not contract so rapidly as the outer layers. This alternate and unequal expansion and contraction of the surface rocks causes them to split asunder and peel off into thin layers, and to this change in the rocks due to differences in atmospheric temperatures the name *insolation* has been given. From what has been said it might appear that there is more weathering of the rocks in arid than in temperate regions. This is not the case. On the contrary, the prevalence of moisture in the atmosphere in temperate regions more than counterbalances the comparatively small daily range of temperature; but the weathering due to moisture proceeds in a way quite different from that due to range of temperature. The disintegration of rocks in arid regions takes the form of splitting into thin sheets. The lack of moisture in those regions reduces to a minimum that other form of weathering in which water percolates through the clefts of the rock and washes away the finer particles of rock. In mountainous districts and in tropical regions the layers of rock that are split off by insolation sometimes fall down the face of the rock and so form a slope of debris called a "scree" or *talus* (see p. 338).

Weathering by Frost.—In cold and temperate regions, where moisture is abundant in the air, frost is the important agent in the process of weathering. First of all, water makes its way into the clefts and pores of the rock, where on freezing it expands and exerts a pressure on the surface rock in all directions. The result is that small fragments are forced to break off when the thaw sets in. These are in due course exposed to the full effects of the atmosphere, or are washed away by succeeding downpours of rain, and so make room for more water to fill up the extra space in the rock from which they came. Even the most durable of rocks are made to feel the powerful expansive force of ice, although permeable rocks are most affected since they permit the water to lodge in their interstices more readily. In very cold regions the destructive action of ice is best illustrated by the work done by glaciers, which carve out valleys in their course along the mountain-slopes and transport their loads of debris down to the low-lying valleys (see p. 470). The work done by the joint action of all the chief weathering agents is clearly apparent in the walls of ancient churches, castles, and buildings, which, unless the crevices in the masonry are " pointed " from time to time, very rapidly fall into complete decay. In large towns their ravages are more manifest because of the large percentage of acid matter of a highly disintegrating nature contained in the smoke and dust of the atmosphere. Snow, unlike frost, is not a powerful agent of denudation. It rather protects than destroys. The mountain plateaux of the Alps afford numerous examples of this protective power of snow. On these the snow lies continuously, and although their edges show unmistakable signs of weathering, the surface of the central portion of each plateau does not appear to have been in any way affected by the denuding forces of nature.

Transporting Agents.—Wind.—A considerable proportion of the work of denudation may be attributed to nature's transporting agents, of which the chief are wind, rain, rivers, the sea, and glaciers. Wind, which is air in motion, has a twofold action. It sweeps away the smaller fragments that have been disintegrated by weathering, and beats them one against the other until they are reduced to the minutest particles of sand. Dust and clouds of sand are also borne by the wind and hurled against rocks, with the result that small particles of the rocks are broken off, which go to swell the next sand-cloud that is swept onwards. Deposits of fine grit and matter have been thus carried from place to place to fill up depressions and create mounds or hills on the earth's surface. Such accumulations of wind-driven deposits are to be found in the Landes, on the south-west of France, and in the Sahara (see p. 179).

Transporting Agents.—Water and Glaciers.—The chemical and mechanical powers of rain disintegrate particles of rock-surface. With succeeding downpours of rain these particles are mechanically carried away to the lower-lying districts by rivulets, and so the surface rock is again laid bare, to be acted upon by the same agencies once more. Thus rain acts as a transporting agent, and also assists in making the soil of valleys fertile, for the debris so transported generally forms a rich alluvial plain. Obviously, the work of rivers and glaciers is to transport matter on a greater scale. In flood-time rivers carry their maximum load in suspension, which they deposit partly in their basins and partly as a delta at their mouths. The Plain of Holland has been formed by the detritus carried down from the Alps by the Rhine, which is fed near its source by over 400 glaciers and snowfields. The Plain of Lombardy, the Valley of the Ganges, and the Basin of the Nile also owe their remarkable fertility to the rivers that traverse them.

Glaciers are in like manner engaged in transporting downwards rocks torn from the slopes of the valleys through which they flow (see Chap. XXXI). These are ground and crushed into smaller particles as the glacier moves onwards, and in this way a fine silt is deposited in the valley below.

The **sea** also helps in the process of denuding the land. The constant action of the waves in beating upon the coastal rocks and in hurling loose stones upon them results in splitting them asunder and washing away to sea the smaller particles which the atmospheric agents have succeeded in loosening. With this there is also going on another action, the waves and breakers throwing up the shingle against the partly eaten coast and grinding pebble against pebble until fine sand is produced. Where the rocks are hard, there the effect of sea-action is less apparent than where they are more permeable or loose in structure.

The Durability of Rocks.—Rocks are of varying degrees of hardness or durability, and all rocks partake of the characters of their constituent minerals, whether soft or hard, cleavable or non-cleavable, and coarse or fine in grain. Granite is possibly the hardest rock to be found in the British Isles. Quartz, which is one of the ingredients of granite, is not greatly affected by weathering; but the felspar in it is, and the felspar by decomposition becomes kaolin, or china-clay, which in England is sent to the Staffordshire potteries from the granite districts in Cornwall and Devon. The durability of granite is clearly seen along the east coast of Aberdeenshire. Here, an almost unbroken line of coast of a remarkably rocky character stretches from Stonehaven to Peterhead, while some distance south the softer and less durable carboniferous limestone of Fifeshire and the Lothians has given way before the combined forces of sea and river and considerably widened the Firth of Forth. Basalt—a hard, dense kind of lava rock—is also of great resistive power. Much of the county of Antrim is composed of this kind of rock, and the basalt pillars which form the entrance to the Giant's Causeway bear little trace of the erosive action of the sea or the destructive power of the weather. Sandstone also has great resistive power, when the grains of sand are well cemented together.

Soils.—From weathering results soil, and on soil grow the plants on which the very existence of man depends. It is from the finer particles of rock that soil is produced, and the depth of the surface coating depends upon two factors: (*a*) the elevation, (*b*) the extent of denudation. In valleys or on slightly inclined plains soil accumulates in many cases to great depths, because the particles of rock, denuded from the more elevated regions, could be carried no further by the many transporting agents in nature. Soils thus formed are extremely fertile and productive, since they contain a very high percentage of rich mineral substances which provide much food for all plant life. On very elevated ground, where the bare rock is not exposed, only a thin covering of soil is to be found, and this coating is usually non-productive because of its shallow depth. Mosses and ferns are the only forms of plant life that can exist in such regions. In districts of heavy rainfall, where there is much weathering of the rocks, the layer of surface soil is of greatest depth and of great fertility. In regions of little rainfall weathering is at a minimum, and therefore there is little or no soil to cover the rocks. In some cases where the rocks are composed of quartzoze material, the soil is merely sand, and a region of low fertility results. Any rain that falls in such districts makes its way easily underground through the permeable sand, and thus the absence of moisture in the ground leads to barrenness. Most of the great arid deserts of the world provide examples of this.

Varieties of Soil.—Soils may be found either lying on the rock from which they have been formed by weathering and decay; or they may have been carried from a distance to their present position by running water or some other transporting agent. Generally speaking, the first kind is soil of low fertility and consists largely of fragments of rock such as white chalk, red sandstone, and limestone. Transported soils, on the other hand, are of very high fertility. All alluvial soils, such as are found along the banks of estuaries and in deltas, belong to this class, as do also disintegrated lava soils, and the drift soils of the glacial epoch (see p. 480). A rough classification is based upon the composition of the soil. According to this method, soils are either clay, sand, calcareous (lime), vegetable, or gravelly, or combinations of certain of these. Sand is the type of what is known as porous or " light " soil; clay is the type of what is known as tenacious or " heavy " soil. When soil contains a mixture of both, the mixture is spoken of as loam, and this class of soil is especially good for cultivation, because of its power of retaining a fair amount of moisture. Neither sand nor clay in itself is suitable for the growth of vegetable matter, since they both err in extremes—sand allowing the moisture to pass through too readily, clay retaining too much and so causing the seed to rot in the ground. Granitic and sandy soils are examples of soils named after the rocks from which they are formed. Granitic soil is very unfertile, because it is generally found only as a slight covering over a hard bed of rock. Sandy soil is in its first stages also unfertile, although it may in time become fertile by the decay of grass and vegetable organisms which gradually occupy it. Vegetable mould is very rich in mineral substances and provides excellent soil for plant growth, the decomposing vegetation giving rise to the formation of *humus* compounds which all go to make the plant strong and healthy. In the regions of heavy rainfall of the tropics (*e.g.* the selvas of the Amazon, and the forest zone of the Congo Basin), where weathering goes on very quickly, the decay of vegetation greatly helps to increase the soil's fertility. But growing vegetation is also a destructive agent. The roots of trees and plants penetrate the crevices and cracks of the underground rocks, and, expanding as the trees grow, they split the rocks asunder or force them upwards to the surface, to be in due course acted upon by the chief weathering agencies. Earth-worms, termites (the white ants of Africa), rabbits, moles, boring molluscs, etc., all do their share in assisting in the formation of soil. They carry decayed vegetation into their homes underground, and turn up the lower layers of soil to the surface. They break up the soil in scooping out their burrows or in casting up the earth as worm-castings on the surface.

Exercises

1. To what extent is the process of weathering responsible for the diversity of form exhibited by mountains ? Does the form of the mountain ever depend solely upon geological structure ?
2. Give an account of the means by which the sea wears away the land. (Camb. Jun. Loc.)
3. What effects does frost produce on the surface of the earth ? Explain these effects, and describe any experiment that would show this particular action of frost.
4. Mention the principal agents that wear away the land, and describe their action. (Civil Service.)
5. What are the chief varieties of soils ? How are they produced, and what are they good for ?

6. Under what conditions is frost an active denuding agent, and how may the results of its action be detected in sedimentary rocks? (Lond. Univ. Inter. Sc.)
7. Give a short account of the action of rain as an agent of denudation. (Civil Service.)
8. What does a farmer mean when he speaks of "light land" and "heavy land"?
9. Describe the changes that take place in the density of water as it cools from 50° F. to freezing-point.

CHAPTER XXVI

Volcanoes and Earthquakes

Temperature of Earth's Crust.—A considerable rise in temperature is observed when a descent is made into a mine, or in a deep well-boring. This increase is due partly to the intense residual heat of the core, and partly to the pressure of rock overhead which gives rise to what is known as dynamical heating. A diminution in temperature due to the release of pressure is spoken of as dynamical cooling. To understand the causation of dynamical heating we only need to work an ordinary bicycle pump. As the pumping progresses the tube is felt to become warmer and warmer, because the air within the cylinder is becoming more and more compressed. Again, the steam that arises from a newly made hayrick is partly generated by the pressure of the upper upon the moisture-laden lower layers, and partly also by the process of fermentation; sometimes the heat thus caused is sufficient to fire the rick. It is so with the earth's interior. That there is great internal heat is proved beyond doubt by an examination of the water and solid matter that is belched forth from within.

Increase of Temperature with Depth.—Up to a certain depth the influence of summer and winter temperatures penetrates into the earth. This limit is known as the *line of invariable temperature*, and it is deepest in regions where the annual range is greatest. After this line the earth grows progressively hotter, and it has been estimated that there is a gradual increase of 1° F. for every 55 feet of descent. This increase is not, however, regular for all parts, because of the difference in rock conductivity, the presence of non-conducting rock-strata, and the existence of subterranean streams of warm water. But we know that the earth does grow rapidly warmer in a downward direction, and at the depth of a mile it has been calculated that the temperature is 100° F. higher than that at the line of invariable temperature. At a depth of 20 or 30 miles the temperature must be enormous, and sufficient to melt any known mineral, and at the core of the earth the temperature is beyond the power of human thought to conceive.*

Causes of Volcanic Phenomena.—The core of the earth is solid only on account of the pressure of the crust upon it. Although this core is at a temperature high enough to melt any known substance, it does not follow that it is in a molten state. The pressure at great depths is enormous, and greater pressure means a higher melting-point (see p. 483). Therefore the core must be in a condition ready to liquefy under reduced pressure. In other words, the core, though solid, is potentially molten. Hence relief of pressure in part of the crust may result in the liquefaction of the core below, followed by more or less violent expulsion. The solid matter is immediately converted into a liquid molten mass and appears on the surface as lava. Relief of pressure takes place in certain places because the core, being still in the process of cooling while the crust has finished cooling, is shrinking away from the crust, forming hollows. The crust is always seeking to accommodate itself to the contracting core, and subsides into these hollows with much straining and crushing. This straining gives rise to earth-tremors, to earthquakes with fractures of the crust, and to volcanic eruptions. In some parts, where the earth's crust is weak and pierced by deep fissures, the molten mass wells up through the fissures and floods large areas. Further, the rocks of the crust are always more or less saturated with water. In the depths of the crust this water can become no more than potential steam. The opening of a crack due to the crushing and straining just mentioned relieves the pressure, and this potential steam flashes into superheated steam with explosive action.

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* Even so, the temperature of the earth's core is below that of the sun.

Definition of a Volcano.—A volcano, then, is a vent in the earth's crust out of which steam, gases, and hot rock issue either occasionally or continuously. The hot rock may be in a molten state, and is then called lava; it may be in the form of pieces or dust. The dust is often spoken of as ash, a term not to be understood as indicating that it is the product of burning. The solid and liquid matter ejected from the vent is mostly piled up around in the form of a mound or cone; but this mound or cone is *not* the volcano.*

Classification of Volcanoes.—There are several ways of classifying the various manifestations of volcanic energy and phenomena. The three most important are grouped under the following heads:

(*a*) *Present Condition.*—This classification is threefold, and regards all volcanoes as either (1) active, (2) dormant or intermittent, (3) extinct. In the case of extinct volcanoes there are often clear traces left of former activity, as in the "puys" or dome-shaped peaks in the Auvergne district of France, where, although no active phenomena have taken place within historic times, the cones have a quite recent appearance. In most cases, however, the usual agents of denudation have removed all superficial evidence, and only trained and systematic searchers can find traces of the volcanic energy of past ages. The basalt plateau of the north of Ireland, Fingal's Cave in the west of Scotland, and some of the Lake District hills in Cumberland and Westmorland are volcanic in origin. Snowdon in Wales is an old volcanic lava-cone. Dormant volcanoes, though showing no sign of present activity, may give ample evidence in the form of tremblings and steam escapes that they are not extinct. Vesuvius was considered dormant up to A.D. 79, when it overwhelmed Herculaneum beneath a deluge of mud, since which time it has been in an active condition. Stromboli, a little island to the north of Sicily, is a good instance of a continuously active volcano, so much so that it acts both as a natural lighthouse and a natural weather-glass, for when wind is threatened under low atmospheric pressure, its activity is strongest, but grows much less in fair weather as atmospheric pressure becomes higher. The distinction between active and dormant volcanoes is not easy; for so-called active volcanoes may be quiescent for long periods, sometimes even for years. As time passes by, soil is formed on the weathered ashes and lava of the dormant volcano, plants grow, and man comes to build farms and villages on slopes that were once rent and swept by the eruption. Volcanic soil is extremely fertile (especially suited to vine-growing), and it is for this reason that the west side of South Italy, which is volcanic, is much more fertile than the east, which is not. This it is which tempts the coming of man; but he almost invariably pays for his coming in the end. Etna in Sicily has rolled streams of lava over the country at intervals for centuries; in 1669, for instance, tens of thousands of persons perished in a lava inundation which lasted for forty days. Hecla in Iceland, with a lava stream 15 miles broad, had its 10,000 victims in the eruption of 1783–5; and in more modern times certain islands in the West Indies, in the South Seas and parts of Japan have been awfully devastated by volcanoes. But man in the long run is a heedless animal, and the prospect of natural terrors has never deterred him from settling in districts that are otherwise desirable.

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* A volcano has been defined as a "burning mountain." But it is often not a mountain and it does not burn.

(*b*) *Matter Erupted.*—Regarding volcanic phenomena from this point of view, we must take account of several manifestations not ordinarily thought of as volcanoes at all. Speaking generally of volcanoes, we mean only those ejecting lava, dust, steam, and rock fragments. The springs in old volcanic districts that violently eject hot water and steam are called **geysers** (see pp. 382 *et seq.*). **Salses** or mud volcanoes are found where geysers act through beds of a muddy or clayey nature. When this is the case, instead of comparatively clear water being erupted, we have mud from which are formed small cones like those in the Crimea. There are mud volcanoes in Iceland, in Java, and in the Yellowstone region of the United States. Mount St. Elias on the borders of Alaska is a volcano of this type. When from the earth nothing comes forth but steam and gases, the vent is called a **fumarole**. The development of these is always a sign that the volcanic energy of a region is dying out. Near Naples is a volcano called Solfatara, which has been dormant for centuries, but which still emits steam and sulphurous acid vapours. Hence, if from a fumarole the vapours are largely sulphurous, it is considered as a special variety and called a **solfatara**. Large deposits of sulphur may therefore be found in and around certain volcanic districts. Sicily, Yezzo in the Japanese group, the Alps of New Zealand, Mount Popocatepetl (sold to an American syndicate some time ago) in Mexico, are for this reason rich sulphur-producing districts.

(*c*) *Various Kinds of Vent.*—Regarded from this point of view, volcanoes are of two kinds: (1) the *pipe* volcano, (2) the *fissure* volcano. The latter of these, in which the vent is a long crack or fissure in the crust of the earth, is not often called a volcano. The former that builds up a cone with a central pipe is usually thought of when a volcano is mentioned. Lava cones have low slopes; cones formed of dust and scoriæ have steep slopes. The open mouth of the vent is called the *crater*; some craters are miles across, but usually much less, and in the craters of extinct volcanoes pluvial lakes are often found (see p. 449).

Eruptive Phenomena.—Eruptions are of two kinds: (1) quiet or effusive, (2) explosive. In the former kind lava rises with but little escape of steam and flows down the sides of the cone. In the latter the matter is blown out by explosion from within. If liquid lava is blown out, it is hurled in revolving masses high in the air, and by rapid cooling there forms on the outside of these bodies of lava a hard crust, and they fall as volcanic bombs. These bombs sometimes burst before they reach the earth. Many volcanoes give quiet eruptions at one time and explosive at another, though so-called quiet volcanoes have often some measure of explosive action. The amount of pent-up steam decides the degree of quietness or explosiveness. In an explosive eruption the first outburst is a rush of super-heated steam, shot many miles into the air. In the upper air this steam condenses to form heavy clouds and rain. By and with the steam are blown out dust, rock fragments, and pieces of lava, which descend again to the earth as a rain of mud, stones, and volcanic bombs. The area covered by this devastating rain and the destruction caused will be made clear in the description of particular eruptions. Wherever there exists a line of fracture in the earth's crust there may be at any time wellings-up of lava anywhere along the line. If the lava spreads out as a thick, slaggy sheet, a lava plateau is formed, such as that of which the Giant's Causeway forms a part, or the plateau of California. If the lava emerges at detached points along the line, a series of lava piles will be built up. The Islands of Stromboli, Panaria, Salina, Filicudi, and Alicudi, in the Tyrrhenian Sea, form such a series of lava cones, but high enough to project above sea-level as volcanic islands. A fissure eruption may be as explosive and as destructive as a pipe eruption, as was the case in New Zealand in 1886, when the famous pink-and-white terraces of Rotomahana were destroyed.* The rough, vesicular, cindery material sent out during an eruption is called *scoriæ*, or cinders. The same name is given to the scum forming on the surface of a lava stream. Lava rapidly cooled under pressure is glassy in appearance, and one variety is called obsidian †; cooled at the surface and full of air-holes it is called pumice.

The Cone.—In a volcanic pile, radiating from the central pipe (fig. 92), there sometimes occur cracks into which flows lava, and this, consolidating there, forms **dykes.** These dykes may lie in the cone horizontally in the form of thick plates, or they may stand in the cone more or less vertically in the form of thick walls. The other parts of the pile—dust, pumice, broken stones, etc. —compacted by the pressure of their own weight and cemented by rain, form the rock known as volcanic tuff.

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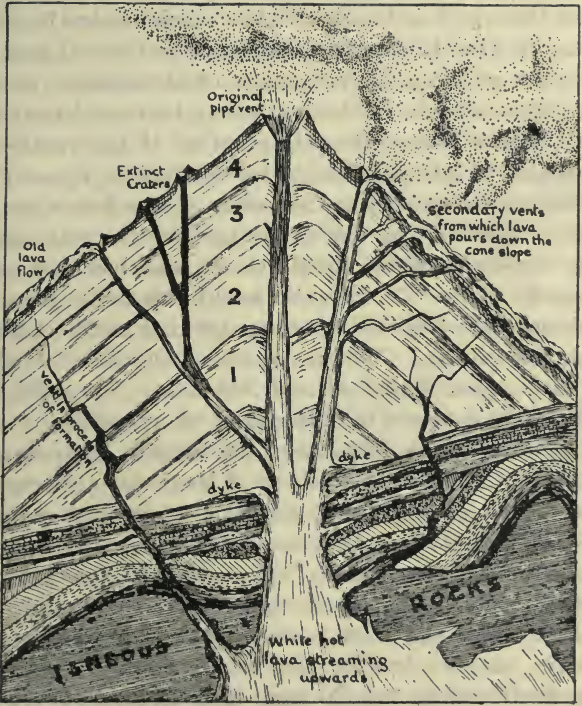
* These terraces are in the process of re-formation.

† Obsidian is in fact a kind of natural glass. The Aztecs of Mexico used it as a material for making sacrificial knives.


Original pipe vent
Extinct Craters
4
3
2
1
Old lava flow
secondary vents from which lava pours down the cone slope
vent in process of formation
dyke
dyke
White hot lava streaming upwards
IGNEOUS
ROCKS

1.2.3.4. Successive stages in the building of the mountain, cone by cone, to its present dimensions. The size of the mountain may be judged by the fact the crater of the original pipe vent is 1000 feet deep. (after MORRELL)

FIG. 92.

Sometimes, the central pipe having become plugged with cooled lava and scoriæ, eruptions take place through subsidiary channels formed along any line of weakness in the old cone. These give rise to lateral craters and cones called parasitic.

Distribution of Volcanoes.—A remarkable fact in the distribution of volcanoes is their proximity to the sea. Of the three or four hundred active volcanoes in the world, all except a few in America and a few in Central Asia and Africa are within a short distance of the ocean. Certain lines on the surface of the earth may be traced out along which active vents—the safety-valves of the earth—are distributed at intervals, and in the intervening spaces there is evidence to show that the subterranean forces are not wholly extinct. This linear arrangement is well marked along the coast of the Pacific Ocean, and has been called a "girdle of fire" round the world. Starting from the southern end of South America, we find in the Andes a continuous line of Chilean volcanoes, the chief of which are Aconcagua, Villarica, and Atacama. Through Peru the line is continued into Ecuador where we find a knot of very lofty cones, including Chimborazo, Antisana, and Cotopaxi. The great tableland of Mexico is entirely volcanic. On this tableland, along the eighteenth parallel, there stretches from west to east a line of five active volcanoes, Colima, Jorullo,* Popocatepetl, Orizaba, and Tuxtla. This line is the commencement of a branch that passes through the West Indies and probably crosses the Atlantic to the Azores. In North America scattered vents are found in the Rockies, such as Fremont's Peak, Pike's Peak, Mount Brown, Mount St. Elias, etc. Then through Alaska and the Aleutian Islands the line is continued to Kamstchatka, at the southern end of which peninsula there is a gloriously imposing group of seven active volcanoes, all between 11,000 and 17,000 feet high. The Kurile Chain is the prolongation of the line southwards into Japan, where among others is Fusi-yama, the holy mountain of the Japanese—the mountain that appears in nearly every Japanese landscape picture. Between the Japanese Islands and the Philippines the line is preserved by several small island vents, chiefly in the Loo-Choo group. After passing southward through Borneo, where is the important volcano called Kini-Balu, the line bifurcates, one branch going north-westward through Java and Sumatra, the other south-eastward through New Guinea to New Zealand. In the Atlantic the lines are not so easily followed. One line may be traced from the north southwards through Jan Mayen's Island, Iceland (which is little more than a huge cinder-heap covered with snow), the Azores, Ascension, St. Helena, to Tristan d'Acunha. The branch line from the West Indies meets this main Atlantic line at the Azores. Another line may be traced from Iceland through the British Isles and the "puys" of France to Italy; but it is a line of extinct volcanoes until in Italy it begins to display active energy in Vesuvius, and continues as an active line through the Lipari Islands to Etna in Sicily.

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* Formed in one night. Pronounce *Horoolyo*.

Among the better known of the world's volcanoes stands **Stromboli.** This is an island cone built up from the bottom of the Mediterranean. The total height above the sea-bed is about a mile. The floor of the crater is black solidified lava containing many cracks. Through the cracks come puffs of steam from the liquid lava boiling below. From time to time fragments of lava are thrown high in the air, and falling on the slopes of the cone, increase its size. At night the glowing lava in the cracks of the lava-floor lights up the clouds which hover over the mountain. Hence Stromboli is known as "the Lighthouse of the Mediterranean."

Vesuvius.—This volcano, 10 miles from Naples, has a main cone 4,000 feet high. The present cone rises within the area of an old crater. Before 79 A.D. Vesuvius was, so far as then known, merely a conical mountain in whose summit was a deep crater 3 miles in diameter, the slopes and bottom of which were covered with vegetation. In the eruption of 79 A.D. half the rim of the old crater was blown away. The erupted matter was mainly dust, which, mingled with rain, produced devastating streams of hot mud. Pompeii was buried in from 25 to 30 feet of this cementing mud, Herculaneum to a depth of 60 feet. The 1631 eruption was very violent, and 18,000 lives were lost. Other eruptions have taken place in 1737, 1794, 1822, 1872, and 1906. In the floor of the present crater are cracks like those in the floor of Stromboli, and in these cracks, during eruptions, explosions may occur as frequently as three times a minute.

Krakatoa.—This was a small volcanic island in the Strait of Sunda between Sumatra and Java. The eruption of August 27, 1883, was one of the most violent and destructive on record. Two-thirds of the island were blown away. There had been earthquakes and small explosions for some years. Then came the mighty catastrophe in which 36,000 lives were lost. The three chief accompanying phenomena were the sea-waves, the air-waves, and the dust-clouds. The sea-waves were so enormous that they travelled half-way round the world. The clouds of dust and steam were shot up 20 miles high, rendering the sky as black as at night. The air-waves, carrying with them the fine volcanic dust, travelled more than three times round the world, their passage being recorded by the barometers at various stations. The course of the fine dust in the air was traced by its colouring effects upon sunsets, and some of the dust was still in the air in Queen Victoria's Jubilee year. The cause of the explosion was probably the same as that of the milder explosions of Stromboli, *i.e.* the sudden escape of superheated steam. The Krakatoa eruption was accompanied by a violent outburst of Kluchefskaya, the highest of the Kamstchatkan volcanoes. The light from this volcano was visible for 250 miles. Earlier (about April) in the same year the ice in the neighbourhood of the Kurile Islands was discoloured with volcanic ash for miles in every direction. These phenomena are all indications of the closely associated nature of volcanic eruptions in different parts of the world.

Mont Pelée.—This volcano is on the island of Martinique in the Lesser Antilles. Before 1902 the crater was half a mile in diameter, and a lake occupied the crater basin 2,000 feet below the rim. On the plain 5 miles south of the volcano stood the town of St. Pierre, with a population of 26,000. In April 1902 sulphurous vapours from the crater became so abundant that horses dropped dead in the streets of St. Pierre. Later in April, the traffic in the streets was obstructed by volcanic dust. On May 5 mud flowed over the lip of the crater like porridge boiling over the edge of a saucepan, and poured down the valley. On May 8 a heavy black cloud of dust, steam, and gases swept down from the crater over the plain, and in two minutes struck St. Pierre. Instantly, buildings were overthrown, trees torn up, and the city burst into flames. A few minutes later a deluge of rain, mud, and stones fell, completing the devastation and wiping out the entire population. The temperature of the steam, vapours, and white-hot dust is estimated to have been over 1,400° F. The chief cause of death was suffocation. There were further eruptions on May 20, May 26, June 6, July 9, and August 30 of the same year.

Soufrière.—This volcano is on the island of St. Vincent, 90 miles south of Martinique. The eruption of May 7, 1902, was in sympathetic action with that of Mont Peléc, and was in every way similar to it, except that, fortunately, no large town lay in the path of the steam-cloud. Of this volcano also there were further eruptions on May 18 and September 3 of the same year. Dust-beds on the island, after the eruption, were found to be in some places as much as 60 feet thick. There was no lava flow.

Hawaii.—This island, built up of lava from the sea-bottom, consists really of four volcanic cones massed together. The eruptions from these cones are relatively quiet. The largest of the four craters, Mauna Loa, is 3 miles long and 2 miles wide. The crater-floor, 10,000 feet below the lip, is hard but hot, and crossed by cracks. Eruptions are heralded by the rising of the crater-floor and the consequent enlarging of the cracks, in which can then be seen lakes of swelling lava. Fountains of lava rise some hundreds of feet above the floor, but none flows over the crater-rim. What lava escapes passes through cracks in the mountain-side, forming streams as much as half a mile wide and 50 miles long. These streams flow faster than a glacier, but slower than ordinary rivers. From these craters there is very little steam emitted; there are no rumblings, no explosions, no dust, and earthquakes are very rare.

Geysers.—The word "geyser" is derived from the Icelandic *geysa*, to gush, so that the word means a *gusher*. We apply the term to a natural spring or fountain which spouts forth explosive gushes of steam and boiling water at more or less regular intervals of time; consequently geysers may be regarded as intermittent hot springs. They are commonly found in regions of volcanic activity.

Causation of Geysers.—To gain a clear idea of the causation of geysers, two things should be borne in mind with respect to the boiling of water: (1) that water on descending to great depths in the earth's interior is prevented from boiling because of the increased pressure; (ii) that the action of boiling causes two currents of water to be set in circulation—an upward warm current and a downward cool current (see *Convection*, p. 17). If the vessel in which water is boiled is tubular in form this circulation is impeded, in proportion as the bore of the tube is narrowed by its sides; if the vessel is large and open, the convection currents are only slightly retarded.

Now consider the rain that falls upon the earth. About one-third of it sinks into the ground, some of which penetrates in many places to a considerable depth. A small quantity of it reappears on the surface in thermal springs. But where the earth's crust is weak or much cracked, or very porous, as is often the case in the neighbourhood of volcanic activity, the water descends to very great depths. There the heat is intense and the water reaches a temperature much above 212° F., but it is prevented from boiling by the pressure from above. It is in a state of *potential steam.* Imagine that a deep opening in the earth's crust is filled with water. The lower layers of water will be sustaining the pressure of the superincumbent column, and this pressure, together with the length and narrowness of the tube which contains the water, will prevent the convection currents from circulating rapidly and so will retard the boiling of the water. In time, however, if the temperature of the water in all parts of the column steadily increases, the temperature at some place down the tube may reach a point which approaches the heightened boiling-point. When this occurs, the superheated water at this point is converted into steam, which by its expansive force belches forth the superincumbent water high into the air. Thus geyser action is caused. Not all geysers are continually or continuously active. In some the explosions take place only at varying intervals, and the time that elapses between successive eruptions varies for different geysers. With some they occur at intervals of a few minutes; with others at intervals of several hours. "Old Faithful"—a geyser in Yellowstone Park, North America, which is noted for the regularity of its eruptions—is in a state of activity at intervals of about an hour's duration, while the period of eruption generally lasts for about five minutes. "The Giant"—a geyser in the same district—has been known to remain in a continuous state of activity for nearly three hours and a half. The intermittent character of many geysers suggests that a certain period is necessary to heat up the new supply of water which enters the pipe after the last lot has been spouted out. The celebrated scientist Bunsen, to whom we are indebted for the theory of geyser action, submitted it after taking numerous observations at various depths of the Great Icelandic Geyser. He found that the temperature of the column of water decreased more or less regularly from the bottom upwards, and that there was a steady increase in temperature all down the column during the interval of time which elapsed between an eruption and the one following; also that the nearest approach to boiling-point (taking into consideration the pressure of the water-column) was not at the bottom but at a point about half-way down the pipe. Relying upon these observations, he performed a simple experiment to illustrate geyser action.

Bunsen's Experiment.—A tube *A* (fig. 93) is filled with water and heat is applied at two points, *A* and *B*. When the water at *A* begins to boil, it expands and raises the column of water in the tube. The water at *B*, which was on the point of boiling, is thus raised to a point where the pressure is less than it was at *B* ; consequently the water there is changed into steam, which by its expansive force ejects the column of water *BD* from the tube. After the eruption the water falls back into the basin *C* at the top of the tube, from which it flows back as a cool stream again into the tube, cooling the whole column. Some minutes will elapse until the lower layers of water in the tube are sufficiently heated before the next explosion and ejection of water occurs.

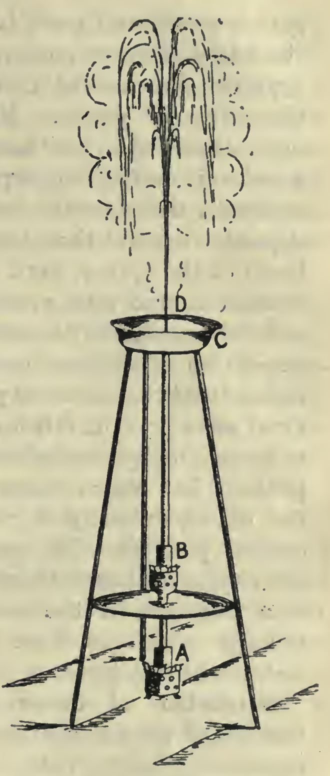

FIG. 93.

Geyser Water and Hot Springs.—Geyser water has at all times been famous for its medicinal properties. Especially has this been so with the water of the geysers in North Island, New Zealand. These medicinal properties are derived from the minerals of the rocks exposed to the action of water during its course underground. The chief substances dissolved are silica and compounds of sodium, magnesium, and other alkaline metals. A very large percentage of silica is usually held in solution by geyser water, and great beds of silica are formed around the edges of every geyser. This deposit is called sinter or geyserite, and is due to the evaporation and cooling of the siliceous waters. Minute plant organisms called *algæ* also assist in the formation of the deposit. Where a volcanic hot spring deposits matter of this kind, it is gradually transforming itself into a geyser. The silica is deposited around the edges and all along the bed of the basin of the spring, until in time it builds up for itself a circular mound with a central tube in much the same way as a volcano builds its cone. Sometimes the effect of this deposition of siliceous matter is to pile up such a large mound that the increased pressure of water in the pipe is so great as to prevent it from working. In Iceland there are to be seen many examples of former geyser action. Large pools of hot water, called by the natives *laugs,* diversify the island, in many of which may still be observed the central pipe that at one time was the scene of great activity. In these districts thermal springs may also be seen engaged in the work of constructing the pipe through which at some future date steam and boiling water will be ejected.

Distribution of Geysers and Hot Springs.—The chief centres of geyser activity are to be found in volcanic regions—notably in Iceland, Yellowstone Park in the Rockies, Mexico, the West Indies, the Azores, Japan, and North Island (New Zealand). In all those regions both geysers and hot springs are to be seen. One of the few swimming-baths heated by natural means from boiling springs a mile away is that in Reikjavik in Iceland. In the district surrounding the Great Geyser, which is situated about 30 miles north-west of Hecla, are about one hundred hot springs within a very small radius. Some of these have a depth of from 20 to 30 feet, the largest of them being called Blesi. The Great Geyser has at the summit a mound built up to a height of 40 feet by successive layers of silica, and the crater is 66 feet in diameter. In the middle is a hole, 10 feet in diameter and 82 feet deep. The temperature of its surface-water varies between 160° F. and 190° F. When in eruption it sends upwards a column of water 100 feet high, and the time between each eruption varies from two to seven hours.

In Yellowstone Park geyser activity on a wonderful scale may be observed. Within a comparatively small area there are nearly 3,000 hot springs and 100 geysers. The most important of the geysers are " Old Faithful," " The Giant," " The Giantess," and " The Castle." " The Giant," although not frequently in eruption, is remarkable for the duration of its eruptions. " Old Faithful " ejects a fountain of water to a height of 150 feet, but it is left to " The Giantess " and " The Castle " to exceed all others in the violent nature of their eruptions. Both of these send up columns of water to a height of 250 feet, amid deafening noises which make the earth vibrate as if it were undergoing a severe earthquake shock.

The great geysers now to be seen in the province of Auckland in the North Island of New Zealand have of late years been remarkable for their activity. During the years 1880 to 1886 they remained in a quiescent state; but in 1886, after a series of gigantic explosions in which several columns of water were driven upwards of 700 feet high into the air, seven new geysers came into being. This change was in a great part due to volcanic disturbances in the island. The Waikite Geyser is the best known of the group.

Earthquakes.—An earthquake is a wave-like movement of alternate contraction and expansion of the crust of the earth caused by some disturbance deep down in the crust. The disturbance is one of sudden movement or fracture at a definite point or along a definite line, and whatever may be the cause of the disturbance, the rocks in the neighbourhood are shaken, and vibrations travel away from the centre of disturbance as an earthquake shock. Even dynamite-blasting operations in quarries will start a shock that may be felt miles away. The two commonest causes of these sudden movements are (1) the relief of tension at some weak spot in a set of slowly folding strata, and (2) the explosion of confined accumulated steam either because pressure overcomes an unaltered resistance or because resistance is in some way lessened. Earthquakes due to the former of these causes are those that cause permanent changes in the relief of the land surface. Other minor causes of earth-shocks are the slipping of strata along fault-planes previously formed, and underground floodings which undermine and render unstable the overlying strata. The fact that the earthquake vibrations, however set up, can be followed, recorded, and even timed,* forms an excellent proof of the great elasticity of the earth's crust; for however rigid rocks may seem to be, they are capable of compression, stretching, and bending. The wave-movement of the earthquake proves the elasticity of the rocks affected; the cause of the wave-movement, *i.e.* a fracture, proves that the elasticity has a limit.

Distribution of Earthquake Areas.—Earthquakes mostly happen along the chief lines of earth movements of elevation and subsidence, and often occur in the same areas as volcanic eruptions, though, so far as we know, there is no necessary connection between the two phenomena beyond the assumption that an eruption is an extreme form of earthquake. The shores of the Mediterranean are subject to sudden earthquake movements as well as to slow crust movements; and the centre of that sea is a region of volcanic activity. Japan is a land where both phenomena are not only common but even carelessly disregarded. South America, too, is a land of earthquakes and volcanoes. Great Britain is not free from earthquakes, though free from volcanoes. Frequent slight shocks are felt in the little Perthshire village of Comrie. During the Christmas week of 1896 a considerable shock attended by some injury and damage was felt along the Welsh marches, the seismic * centre being somewhere in the crust below Hereford. Even Ireland is not free from such disturbances. Minor shocks are often felt in the counties of Wicklow and Donegal.

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* In the late Professor Milne's laboratory at Shide in the Isle of Wight are delicately poised instruments which tell when an earthquake has occurred, and draw a graph showing its intensity even when it occurs on the other side of the globe. The apparatus is called a seismometer, and there are about a hundred seismic observatories in different parts of the world.

Results of Earthquakes.—When an earthquake affects the sea-floor, especially when its origin is below the sea-floor, the sea is violently agitated and mighty oscillations of the waters are set up which, when they reach the shore, become huge breakers and do much more damage than the earth-waves upon which they attend. In the great earthquake of Lisbon on November 1, 1755, the shock of the jar in the crust was sufficient to bring the city to a heap of ruins in ten minutes, but it was the huge sea-waves that brought about the death of 35,000 people. The same form of double destruction was dealt out to Messina and Reggio in 1908. Besides the destruction to life and property, earthquakes produce results that may modify the physical geography of a region. Surface cracks appear which afterwards become permanent waterways, the slope of the land may be changed, and the courses and rates of flow of streams may be altered. These results actually followed the great Japanese earthquake of 1891, the Assam earthquake of 1897, and the Cutch earthquake of 1819. The great Japanese earthquake of 1891 caused a split 40 miles long in the ground in the valley of the Neo. On one side of this fault the ground subsided as much as from 15 to 20 feet.

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* The centre of shaking.

Man and Earth Disturbances.—The regions of earth disturbances are by no means shunned by man. In Japan and in South America earthquakes are regarded as nothing more than the ordinary risks of life. By building special kinds of houses * and bridges the people endeavour to minimise the possible destruction and loss, but the possibility of loss of either property or life does not drive them to forsake even the most menacing areas. Lisbon, Kingston (Jamaica), San Francisco, and Messina are still flourishing centres of population and wealth, in spite of many threats of extinction. There is no soil so fertile as that formed of volcanic lava and dust, and this, together with the fact that man quickly forgets disagreeable things, easily accounts for the dense population in the neighbourhood of Pompeii and Herculaneum.

EXERCISES

1. State the causes of

(*a*) The violent explosions that occur during a volcanic eruption ;

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* The lightly built wooden house of Japan has been called " the child of the earthquake."

(*b*) The darkness that often exists during the day when an eruption is taking place ;

(*c*) The bright glow that is seen above a volcano at night ;

(*d*) The lightnings that accompany volcanic outbursts.

2. Write a short description of the World's "Girdle of Fire."
3. What are the chief secondary effects and accompaniments of earthquakes ? Where possible, give concrete examples.
4. Distinguish between scoria cones, pumice cones, tuff cones, lava cones, composite cones, and parasitic cones.
5. What reasons are there for believing that a high temperature exists in the interior of the earth ? (Camb. Jun. Loc.)
6. Why is there often a dense population in regions of present volcanic activity ?
7. Write a short account of the famous Krakatoa eruption.
8. Of what materials are volcanic cones composed and how are they arranged ? (Camb. Jun. Loc.)
9. Draw a diagram showing the structure of a typical volcano ; and describe the distribution of volcanoes on the earth. (Camb. Sen. Loc.)
10. Describe some one district in the British Empire which is characterised by considerable volcanic activity. (Oxf. and Camb. Sch. Cert.)
11. State what you know of the distribution of volcanoes over the globe. (Civil Service.)
12. Give an account of the distribution of volcanoes on the earth, and point out any relation between this distribution and the general relief of the land

surface. Describe the principal effects of volcanic action on the form of the land. (Oxf. Sen. Loc.)

13. Describe "mud-volcanoes" and eruptions of mud, and explain their causes and effects. (Lond. Univ. Inter. Science.)
14. What are the principal products given out by an active volcano? Describe the structure of a typical volcanic cone. (Camb. Jun. Loc.)
15. Describe the effects of an earthquake near a sea-coast. What regions of the globe are specially subject to earthquakes? (Civil Service.)
16. How would you recognise a region of volcanic formation, if you were travelling through it? (Oxf. Jun. Loc.)

CHAPTER XXVII

Springs

Causation.—Of the rain-water that sinks into the ground, a certain proportion reappears on the surface. It oozes out through clefts in the rock, and so forms a **spring.** Why this is so will be readily grasped by performing a simple experiment. Take a few handfuls of fine sand and pile them on a layer of hard clay or plasticine. Mould up with your hand a small circular opening on the summit of the sand and pour some water gently into it. Shortly, little streams of water will be observed to trickle out on the surface of the mound along the line that marks the meeting of the clay and sand. The clay is less pervious—that is, it is more difficult for the water to get through it—because it is more compact, and composed of finer particles than the sand. On the summit or slopes of a hill the rain that falls and soaks into the ground makes its way easily enough through pervious rock, but only a relatively small amount can penetrate a slightly pervious rock. The rocks that are most pervious to water may be classed in order of porosity, as: (i) loose sandstone; (ii) limestone with cleavages and cracks; (iii) rocks with cavities mechanically or chemically produced. We may easily test for ourselves the degree of permeability of rocks by taking various marked samples, such as granite, limestone, sandstone, marble, etc., and drying them carefully for some hours in an oven. We then weigh and note the weight of each, soak them in water for an hour or two and weigh again, comparing the second weight with the first in each case. The difference in weights will show us the relative permeability of the rocks. If all strata were of the same degree of permeability as the harder rocks and did not absorb the water that fell upon them, rivers would become violently flooded after each downpour of rain, and would then go dry till the next rain. In fact, the very serious floodings of the Murray and Darling Rivers in Australia and the welcome but lesser floodings of the Nile in Egypt are partly explained by the impervious beds of rock that bound their basins (see also p. 217). The same conditions obtain on a smaller scale in South Africa. In a drought the surface of the Karoo Plain is baked as hard as a brick, and rain, if a sudden thunder-shower chances to fall, runs off it as does the water off a fishmonger's slab. This causes very formidable and sudden floods, of extremely short duration, however, if the flood is due only to a passing shower. A South African river-bed may be dry at one minute and may literally in the next five be changed into a roaring torrent. Hence a traveller in South Africa, on arrival at the bank of a river, never camps on the near but on the far side, whether that " river " has water in it or not.

The proportion of water, therefore, that sinks in at any place on the earth's surface, depends upon the hardness of the rock it meets with. Further, it should be noted that when we use the terms pervious and impervious as applied to rocks, we use them in a relative sense, for no rock is absolutely impervious. It is, however, clear that water that has travelled more or less readily through a pervious stratum underground will be prevented from continuing its course on meeting with a more or less impervious one, and will consequently be forced to flow along and flow *down* the surface of this rock until it can find an exit. During the later course of such a subterranean flow the waters will be constantly replenished by a further supply coming from the pervious rock above, so that, at its exit, it forms a stream of running water called a *surface spring*. Water obtained from these springs is very clear and pure, because it is all the time being filtered as it travels underground. It is also of a fairly low temperature, since it does not penetrate to any great depth.

Again pile some sand on the top of a circular layer of clay, but before doing so cut out along the surface of the clay two or three grooves radiating from the centre. Pour some water gently on the sand, as in the previous experiment, and note where it now makes its appearance along the outside of the mound. It will be seen to emerge at those points where the ends of the grooves terminate. This explains why in many cases surface springs do not occur all along the side of a hill where the hard stratum of rock outcrops. As the water soaks through and reaches the impervious rock it meets with inequalities on its surface, and so, finding as it were paths, forms subterranean channels or streams which finally make their egress on the hill-slope.

The Water-table.—The presence of surface springs depends upon the height of the " water-table "—that is, the limit below which the height of the water in the porous bed never sinks. The water-table is either a curve, or, below an uneven surface, a series of curves undulating with the surface.

In diagrams 94 (a) and (b) the line XY represents an impervious stratum, above which rests a pervious bed, the position and porous nature of which enables it to receive water. As water or rain falls upon this bed, it sinks through the rock until it reaches the level of XY; but when the curve of the water-table is sufficiently great, there will be a movement of the water from the higher to the lower part (modified only by capillary attraction, which is responsible for a certain permanent level in every rock). Therefore in (a) the spring at X is permanent and at Y intermittent—that is, it flows only when the surface of the water reaches a point M sufficiently above the level of Y; and in (b) it is permanent at X and Y because there is a sufficient head of water above both points.

Various Forms of Springs.—Consider that the horizontal line XX_1 (fig. 95) marks the division between a pervious bed of sandstone and an impervious bed of clay beneath it. The water makes its way readily through the softer to the harder rock at XX_1, and the upper layers of sandstone contain less water than those underneath, the layer next to XX_1 containing most of all. This layer is then said to be saturated. In wet weather the limit of saturation rises, whereas in dry weather it falls. When it falls to such an extent that its level is barely above XX_1, then the spring runs dry. This can happen only during the summer months. In winter, however, the heavy rains frequently cause the level of saturation to rise above the water-table, and during these months it seldom falls below it. A glance at the diagram (fig. 95) shows that there is more water at Y than anywhere else on the water-table. This is because sufficient water must accumulate all along the impervious bed of clay to overcome the friction which

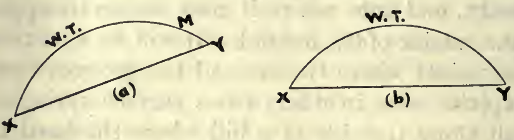

FIG. 94.

is entailed by its flow as it attempts to make its exit. The greater the distance the water is away from the point of exit, the more pressure is necessary to enable it to force its way outwards, so that the column of water at *Y* will be higher above the level of the impervious bed than at any other point on the table. Assuming that sufficient water has accumulated at *Y* to overcome friction, a flow of water will be set up all along the line XX_1, and permanent springs will be formed all around the hill, since the point *Y* is higher than either *X* or X_1.

An examination of fig. 96 shows an impervious bed meeting a pervious at an inclination to the horizontal plane. Here the height of the water-table XYX_1 above *X*

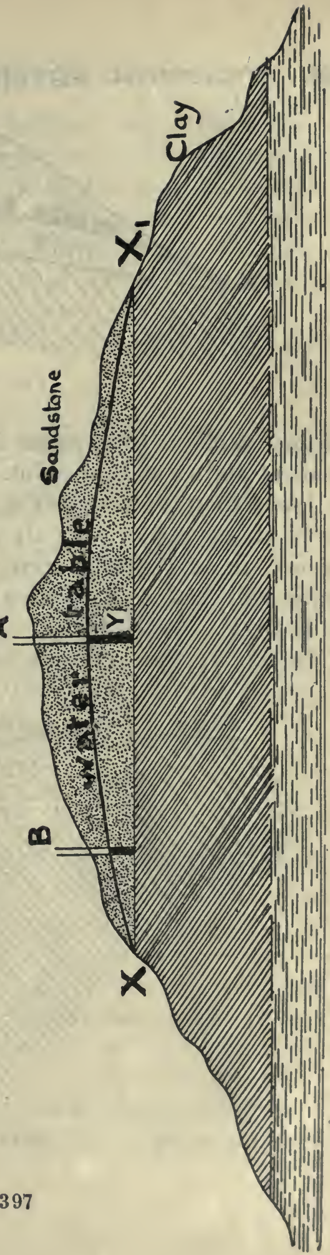

FIG. 95.

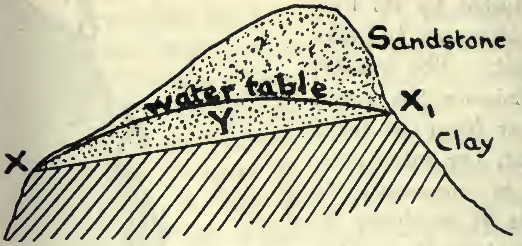

Fig. 96.

clearly explains the reason for the existence of a permanent spring at that point. But since the level of *Y* is lower than X_1 no water can flow out at X_1 unless the level of saturation rises above the level of X_1. If this occurs, an intermittent spring will be formed at X_1, for water will cease to flow when the level of saturation again falls to *Y*.

In fig. 97 the pervious bed of sandstone is wedged

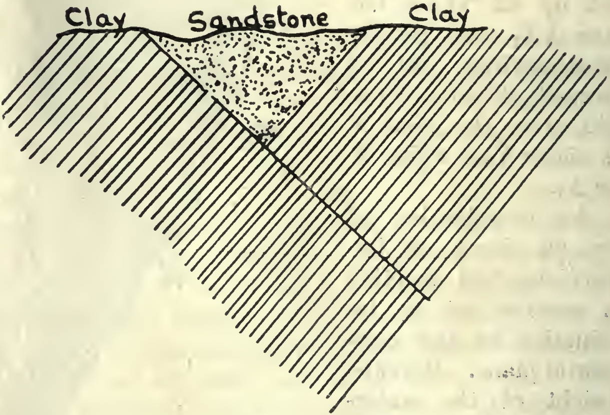

Fig. 97.

between two impervious beds of clay. Here the rain that falls on the sandstone has no means of egress, being prevented from flowing out by the impervious clay on either side. The sandstone is, therefore, in a state of permanent saturation. No springs can be formed, and the only way in which some of the water can escape is by evaporation from the surface.

Fig. 98 at first glance seems to be more or less similar to fig. 97. Two beds of impervious rock are shown with a bed of sandstone wedged between them, but the surface of the sandstone is a sloping and not a flat one. When the level of saturation rises above the water-table, water will begin to flow out at X; but when the level of saturation falls to the level of the water-table, the spring ceases to work. Hence there is an intermittent spring at X.

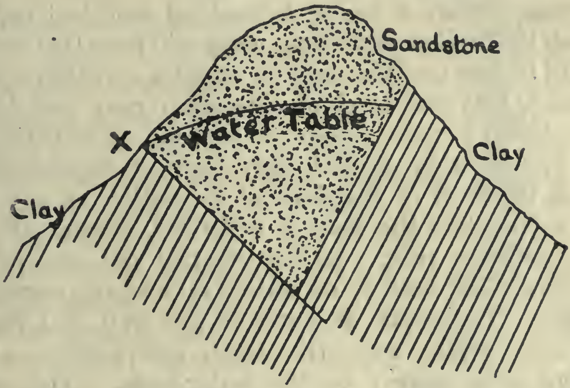

FIG. 98.

Intermittent springs also occur when water collects in underground pools or reservoirs in the rock, and then finds its way out through curved passages that act as siphons. When the water in the reservoir rises above the bend of the siphon, it begins to flow and continues to do so till the level of the water is reduced below the bend, when it ceases to flow, and allows the reservoir to fill again. Sometimes this filling and emptying takes place very rapidly. A spring at Colmar in Alsace rises and falls several times within the hour; in other cases weeks intervene between the two states.

Wells.—When a boring is made of sufficient depth to reach the level of saturation, water will from that moment begin to flow into the shaft on all sides, and thus a well is formed. As the level of saturation rises and falls in proportion as there is more or less rain, so will the depth of the water in the well vary, since it depends chiefly upon the level of the limit of saturation at any time. In wet weather the shaft is well filled, because the level of saturation rises. In dry weather the well may be empty, if the level of saturation falls to any appreciable degree. The depth of water in the well also depends to some extent upon the depth and position of the boring with respect to the water-table. The porous rock becomes more nearly saturated by absorbing water, and retains this water until sufficient has been accumulated to generate enough pressure to cause it to flow. For this reason (see p. 396) the water-table naturally takes the form of a curve, so that if a well is sunk at *A* (fig. 95) it pierces the head of the curve and will therefore have a higher water-level than one sunk at *B*, which is nearer *X*. Wells (like *B*) that are situated near the point at which the impervious bed outcrops, are likely to run dry in warm weather, whereas wells sunk so that they pierce the summit of the water-table are not liable to do so.

Artesian Wells.—Frequently borings are made to considerable depths before the point of saturation is reached, and even impervious rocks have to be pierced before water is found. Where very deep borings have been drilled, the water found must have travelled underground for several miles. Now suppose a hose-pipe is affixed to a water-tap in your garden and the water is turned on. By holding the hose-pipe in a vertical position a spray of water may be sent upwards to a considerable height. The height to which the water rises is due partly to the concentration of water behind the nozzle of the pipe and partly to the pressure of the water, derived from the height of the reservoir from which it comes. Reservoirs are always constructed on some height overlooking the towns they supply, so that the pressure may be sufficient to drive the water up to the highest points within the town. So, too, it is essential for the sinking of artesian wells that the water-bearing strata

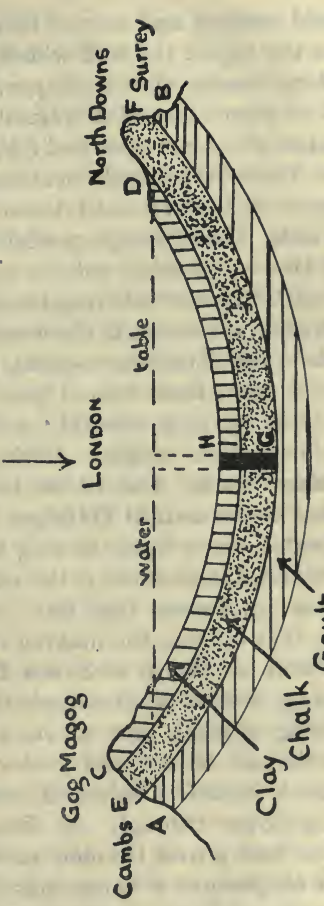

FIG. 99.—The curve of the basin is much exaggerated.

should outcrop and receive their rainfall at a higher level than the top of the well which taps them.

Now imagine that an impervious bed of rock outcrops at two places *A* and *B* (fig. 99), and that above it, but separated by a pervious bed *EF*, is another impervious bed *CD*. The rain that soaks in at *E* and *F* flows down along the impervious bed *AB* until it reaches the lowest level of the bed at *G*. Here the porous chalk bed will become saturated and the water-table will be represented by the broken line *AB*. If now a boring be made at *H* it will be found that when it reaches *G* the water will burst upwards as far as the level of the water-table, because of the great pressure of water from behind (just as it does in issuing from the hose-pipe), the level of its discharge being lower than the level of its supply. Borings of this kind are called **artesian * wells.** One of the best known in this country is that to be seen in Trafalgar Square, London. Part of the water comes from the Gog Magog Hills in Cambridgeshire and Lincolnshire; the other part from the North Downs in Surrey (fig. 99). Another arrangement of beds that favours the making of artesian wells is such as is found at Bourn in South Lincolnshire. The water-bearing bed is a limestone of considerable thickness, covering a large area at its outcrop. It dips in the direction of Bourn and grows thinner as it dips. At Bourn it is 90 feet below the surface. The water percolating down through the limestone becomes pent up as the bed grows thinner, and when it was pierced in 1870 to procure a water supply for Spalding, the pent-up water rose with such force as to damage the boring apparatus. In Australia (especially in Queensland, New South Wales, and South Australia) artesian wells have been bored in many places. In the dry Riverina

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* From Artois in France, a district in which they were first sunk.

District, New South Wales (where the deepest bore is carried to a depth of 4,341 feet), they have proved of immeasurable service to the farmers in providing them with water for their sheep and cattle during long periods of drought. Artesian boring has also been of immense use in the Sahara, where the drainage off the southern slopes of the Atlas Mountains soaks in. It may be noted that the underground supply which the Australian wells tap is part of an underground creep of water that slowly makes its way to the sea. The fresh water, having reached the sea, sometimes wells up from the sandy sea-bottom as submarine springs, and off the eastern Australian coast fresh water is sometimes taken up in buckets *at sea*. The same phenomenon is observable off some of the oceanic South Sea islands; there the natives dive down and fetch up fresh water from the sea-bottom in gourds. Off the Atlantic coast of the United States "ground ice" has been noticed to rise off shallow sea-bottoms in the winter-time. This is due to the fact of an off-shore freshwater creep welling out into sea-water which is below freezing-point.

Mineralised Springs.—Place a little quick lime in a bottle of clear spring-water. Shake the bottle well and observe that the lime dissolves in the water. After a while, by absorption of carbonic acid from the air, the dissolved lime becomes insoluble limestone, and when the water is at rest this limestone will settle on the bottom of the bottle as a sediment. If a small stick be placed in water that contains a very large percentage of lime and allowed to remain there for some time, a thin layer of limestone will be seen to coat it. Water containing limestone has, therefore, the effect of encrusting (sometimes called "petrifying") a body. Springs found in limestone districts, like those in the north of Ireland, the Pennines in Derbyshire, and West Somerset have this property and are termed calcareous springs. All mineral springs are named after the mineral held in solution. Springs that contain in solution a fairly large amount of iron, mainly ferrous carbonate, are called ferruginous or chalybeate. These springs are famous for their medicinal qualities. Some of the best known in England are those of Tunbridge in Kent. When water percolates to great depths, it becomes heated and issues out on the surface as a hot or thermal spring. These springs contain a large percentage of mineral substances, owing to the depth of their source and the nature of the rocks traversed. At Bath the temperature of the water reaches 115° F. Thermal springs are, however, as might be expected, most common in volcanic districts. Several towns in England and on the continent are noted for the quality of their "waters." Among the best known are Cheltenham, Leamington, and Harrogate in England, and Carlsbad, Marienbad, and Vichy abroad. The water of the springs in these places contains many substances in solution, such as salt, sulphur, carbonate of lime, iron, etc., all valuable medicinal agents. Petroleum is discharged with the waters of many springs, as in the Auvergne; but in some cases the oil itself rises in springs, as in the case of the famous oil-wells of North America and of Trans-Caucasia. In the well-known Pitch Lake * of Trinidad there is an enormous supply of asphalt.

Saline Springs.—Springs that contain salts in solution are known as saline springs. They are very numerous in Cheshire, Worcestershire, and South Durham opposite Middlesbrough, where, because of the large percentage of common salt held in solution, they are called brine springs. The manufacture of salt is an important industry in these districts,* and the method by which the salt is obtained at the different centres is to pump water into the mines until it is saturated, when it is again pumped back to the surface and the salt extracted by artificial evaporation of the water.

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* Petroleum and asphalt are liquid and solid varieties respectively of bitumen.

Petrifaction.—Rain-water in falling through the air dissolves carbonic acid gas and so becomes acid to some small extent. Water exposed to the air will also for the same reason become slightly acid. Therefore all natural waters are able to dissolve some portion of the limestone rocks through which they pass, the dissolved limestone becoming hydrated carbonate of lime. Thus at Matlock in Derbyshire the water contains so much carbonate of lime that objects allowed to lie in it for some time become coated with it. The water of Lough Neagh in Ireland has this petrifying power. As a result of the ease with which water containing carbonic acid dissolves limestone, rocks composed of this substance are often worn into caves and hollows. Sometimes the carbonated water filters through the top of a cave and falls to the floor, leaving on both roof and floor some of the limestone it held in solution. These deposits increase in quantity in the course of time, until icicle-shaped spears of limestone called **stalactites** hang from the roof, and rounded masses called **stalagmites** form and rise up from the floor. When these meet, solid columns reach from the top to the bottom of the cavern. Columns like these may be seen in course of construction in nearly all limestone caverns. A specially fine example exists in a cave on the Isle of Caldey near Tenby, South Wales.

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* Noted salt-centres are Nantwich, Middlewich, and Northwich in Cheshire, and Droitwich in Worcestershire—all names ending in *wich*. Now, salt used to be obtained by evaporation of sea-water in shallow *wiches* or bays, as the word "bay-salt" remains to testify. Hence any place for making salt was called a *wich*, and thus it is that the four inland salt-making towns have acquired their names.

Hard and Soft Water.—Pour some water containing carbonate of lime into a basin and try to wash your hands in it with a piece of soap. The soap curdles in the water, and a lather can be produced only with difficulty. The lime in the water produces with the soap insoluble curds of stearate of lime, and until enough soap has been used to remove the carbonate of lime the water will not give a lather. Such water is called "hard," while water in which soap dissolves freely and produces a lather readily is called "soft." Boil some of this hard water, and when it is cool wash again with soap. This time the soap dissolves and a lather is produced. Therefore, water which is made hard by carbonate of lime can be softened by boiling. If you look inside a kettle in which hard water is constantly being boiled you will see there the deposits of carbonate of lime adhering to the sides and bottom. Hardness of water due to the presence of carbonate of lime is called temporary hardness. Distilled water and rain-water are both soft. If you harden some water by adding a pinch of powdered gypsum (sulphate of lime), you will find that boiling will not soften it. This kind of hardness is called permanent hardness.

EXERCISES

1. What is the cause of the intermittent action of geysers? How is it that objects thrown down the tube of a geyser will sometimes give rise to an eruption?
2. Explain, with diagrams, the mode of origin of the different kinds of springs. How does the water of springs differ in composition from rain-water, and what is the cause of the difference?

3. A certain hill is composed of sand at the top, then chalk, and lastly clay, near the bottom. Whereabouts on the hill-side would you expect to find springs of water? Also explain how it is that different kinds of rocks are often arranged in layers one above the other. Are similar kinds of rocks being formed anywhere now? If so, where, and how?
4. What differences are there between rain-water, spring-water, and sea-water? What experiments would you perform in order to show the differences? How do you account for the differences?
5. Give an account of the underground circulation of water. Draw and explain a diagram illustrating the construction of an artesian well. Mention any part of the world you know, and particularly any part of the British Empire, in which such wells are of great importance in agriculture. (Civil Service.)
6. How do you account for hot springs? Name a few of the more remarkable hot springs, and describe their position.
7. How do natural springs arise? (Camb. Jun. Loc.)
8. Describe shortly conditions which may give rise to a *surface spring*. (Oxf. Jun. Loc.)
9. Give an account, with diagrams, of the structure of the London basin. Explain how, in some cases, London obtains water from artesian wells. (Northern Univ. Matric.)
10. In some parts of England the inhabitants derive most of their water-supply from deep wells. Give examples of such parts, and explain why it is necessary to resort to this method. How is it that water can be obtained in this way? (Oxf. and Camb. Sch. Cert.)

CHAPTER XXVIII

Rivers and their Work

Origin of Rivers.—The rain and the snow that fall upon the land are drained away by streams and rivers flowing towards the sea. A river consists of a **main stream,** into which flow from all parts of the drainage-area numbers of subsidiary streams called **tributaries.** The place where a stream commences is called the **source.** In a very mountainous region the main stream or its tributaries may originate at the snout of a glacier, as is the case of little rivulets that unite near Mount St. Gothard to form the source of the Rhine; in a country of lesser elevation the source of a stream may be a lake among the hills, as is the case with many small rivers in the north of Scotland; or it may be a hillside spring or springs, as is the case in the four head-streams of the Thames. A good deal of the water that sinks into the ground issues again as springs and finds its way into river-valleys after an underground course. Thus river-valleys carry to the sea the water both of underground and of surface drainage. The region drained by a river and its contributing streams is called the **basin** of that river. Which of the streams in a basin shall be called the main stream is a question generally settled by the people living in the basin; but when one stream has been selected as the main stream, all the other streams are called tributaries.

For convenience, geographers have agreed to name the banks of a river right and left according as they are so when the observer stands with his back to the source and looks in the direction the river is flowing. Dividing one basin from another, there is always some land, more or less high, that causes the falling rain or melted snow to go into either the one basin or the other. This high ground is called the **watershed, water-parting,** or **divide.*** There is, for instance, a slight ridge a few hundreds of feet high which crosses the plain of North America. This ridge on its northern edge is called the Height of Land, and on its southern the Great Divide, and it divides or parts the sources of the Mississippi, the St. Lawrence, and the Red River of the north. In Europe a belt of highlands and mountain ranges crosses the continent, roughly speaking, from the south-west to the north-east, and forms the continental water-parting.

How to Draw a Water-parting.—Draw a map of Europe, and mark with fine pencil lines the main streams of all the larger rivers. Join by a straight line in ink the source of each river to its mouth, and mark all the sources with large dots. You will then have a double row of dots crossing the continent along the line of the main water-parting. Where the two rows come close together the divide is a narrow ridge, where they separate widely the divide is a more or less broad plateau. Scandinavia has a detached water-parting of its own. Draw a similar map of the other continents, and note such remarkable features as the long slope of the northern rivers of Asia, the great breadth in places of the divide in the same continent, the closeness to the west coast of the divide in both North and South America, and so on. The exercise may be extended and subsidiary watersheds indicated by drawing straight lines from the source of chief tributaries to their confluences with the main stream, and putting the big dot at each source.

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* A distinction is sometimes made between watershed and water-parting by considering the water-parting as a particularly distinct and well-marked watershed. Thus the Pennines would be called a water-parting, and the Pennine spurs that separate the tributaries of the Yorkshire Ouse would be called watersheds. Professor Huxley suggested that watershed should denote the slope along which the water flows, and water-parting should denote the summit of this slope.

Rivers as Drains.—That rivers effect the chief drainage of a region is true only of the less civilised countries; and the more civilised a country becomes the more is the drainage helped by artificial means. It is a commonly known fact that farmers place drain-pipes in their fields and meadows, so that when the water in the soil *rises* to the level of these pipes it may flow along them into a ditch at the lower end of the field. Somewhere in the neighbourhood will be cut what is called a **catch-water** or a **catchment drain,** into which all the ditch-water flows; the catchment drain carries its water to the nearest stream, which may be either the main stream of the basin or one of the tributaries. You have also seen the rain fall in the streets of a town and flow off the camber or crown of the street to the gutters, finally disappearing down a grating. This surface-drainage water is carried by pipes to the nearest stream which takes it to the sea. The drainage of surface-water off country roads into the side ditches follows the same plan.

The Work a River Does.—Besides the general work of draining the land which is done by the river as a whole, there is other work done by various parts of the river which may be called the departmental work. Such work may be conveniently divided as follows: (1) Wearing away its banks and bed; this is the work of **denudation.** (2) Carrying away the worn-off material; this is the work of **transportation.** (3) Laying down this material elsewhere; this is the work of **deposition.** These different kinds of work are done mainly by different parts of the river, *e.g.* denudation is done in the upper course, transportation in the middle course, and deposition in the lower course. But it must not be supposed that there is any sharp division where one kind of work ends and another begins.

Denudation.—This work of a river may be done in two ways, chemically and mechanically. Instances of chemical action are not so common as those of the other kind. Usually they take place together, the mechanical action predominating, except in limestone regions. Mechanical denudation may be called **erosion,** chemical denudation **corrosion.** Both forms of denudation depend upon what is in the water of the river. Corrosion cannot take place unless there is in the water something that will make it slightly acid. This is obtained from the air by rain-water which dissolves out the carbonic acid gas, or from certain acid substances dissolved from decaying vegetable matter with which the water comes in contact. Erosion cannot take place unless there are particles of solid matter in suspension in the water. These being present, the water as it flows acts upon the banks and bed in the manner of sand-paper. And just as sand-paper does more or less work according as the rough particles are bigger or finer, and according as the paper is energetically or sluggishly used, so the river does more or less erosive work according to the size of the particles in suspension, and according to its velocity. All that a river carries is called its **load.** This load may be carried in suspension, carried in solution, or rolled along the bed. Now the faster the water flows, the more load it can carry, and the bigger particles can the load consist of. But there is a limit to the load, and when a river is carrying all possible, it is said to have its *maximum load.* The maximum load depends upon (1) the velocity of the river, (2) the volume of the river, (3) the fineness of the material composing the load. When a river has a full load and its velocity is checked, some part of its load is deposited. When a river has a full load and its velocity increases, it wears away its bed, increasing the load towards the maximum possible with the new velocity. Let *ABC* (the unbroken line, fig. 100) represent the original slope of a river flowing over a uniform bed from *A* to *C*. At *A* there is no load, therefore no erosion. Between *A* and *B* a load is collected—through the wind blowing dust into the water, through the weathering of the banks, through rain beating soil into the water, and so on. At *B* there is *some* load, but if not a *full* load, then erosion takes place and the slope increases down the dotted lines. If, however, there is a full load by the time the river reaches *B*, erosion must have taken place along the steeper slope from *A* to *B*; consequently at *B* there will be a check in velocity, some of the load will be deposited, and the slope will be lessened. Hence the bed of the river tends to assume the shape of the lower dotted line. A horizontal line drawn backwards from *C* represents the lowest level along which the river finally flows (*i.e.* sea-level). This is called the **base-**

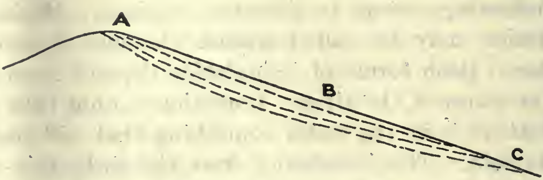

FIG. 100. (The slope is exaggerated.)

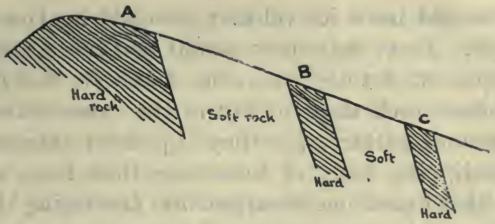

FIG. 101.

level, and it is towards this level that the curve of erosion (shown by the dotted lines) is always tending. The curve of erosion seldom falls below the base-level, and so, as the point *A* is being continually lowered by erosion, the erosion-curve tends to coincide with the base-level. That is, the base-level works backwards from *C* towards *A*. This is spoken of as the river cutting its way back into the hill. Rivers of this type, flowing over a uniform bed, are not common. The short rivers flowing over the boulder-clay plain into Robin Hood's Bay are examples.* But beds of a clayey nature or of soft sandstone are more easily worn away than slate, limestone, or grit, and so if the slope and the arrangement of the beds should be as in fig. 101, then a river flowing from

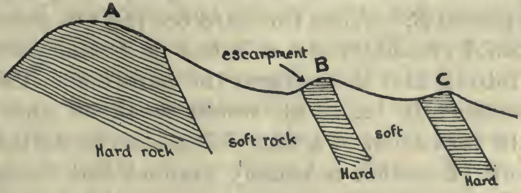

FIG. 102.

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* The boulder-clay plain behind Robin Hood's Bay, in Yorkshire, is a plain of deposition ; the coastal plain on the south of the Gulf of Mexico is a newly uplifted plain and is drained by rivers of this simple type.

A to *C* would have its velocity checked by the beds of hard rock. Later its course would be turned and ridges or escarpments formed as in fig. 102. In this case the beds of hard rock slope or *dip* in the same sense as the upper ground surface, *i.e.* they dip down-stream as do the east-dipping beds of limestone that form at their *outcrop* the limestone escarpments traversing England from the south coast to the northern parts of the east coast. The Trent and the Great Ouse are examples of rivers turned to flow by the side of, instead of over, beds of hard rock. But if the hard beds dipped in the other sense, *i.e.* up-stream, as at *B* in fig. 103, the stream flowing from *A* to *C* would not begin to deepen its bed until it passed *B*. When this hard bed (*B*) was passed, the river would encounter the soft bed at *C* and commence to cut into it, and to undercut the hard bed. This bed, when sufficiently undercut, would break off and finally allow the formation of a waterfall along the dotted lines. The work of erosion is usually gradual and continuous, but in flood-time it becomes much intensified, and often one short period of heavy rainstorms will do the denuding work of many years of ordinary rains.

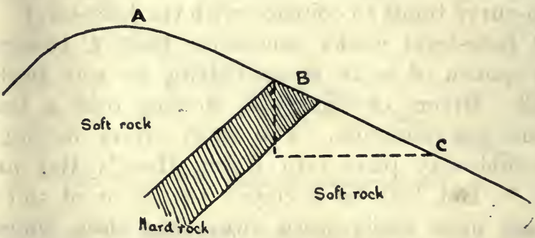

FIG. 103.

Transportation.—The matter transported by a river may be either invisible, as is the case with substances in solution, or visible, as is the case with detritus in suspension. In a limestone district the load of the rivers will largely consist of lime salts in solution. It has been estimated that the Thames carries to the sea daily a thousand tons of carbonate of lime. The Dee, in Scotland, which flows through a granite region, carries to the sea no more than traces of dissolved mineral matter. In a sandstone or a clay region the load will be mainly mud, sand, or gravel in suspension. The total amount of the visible load carried to the sea daily by the Mississippi has been estimated at sufficient to cover a square mile of area nearly a foot thick. The Hoangho carries about three times as much as this. The Po is pushing out its mud deposits across the Adriatic at such a rate that it has been estimated that in about 1,000 years the Gulf of Venice will be converted into an inland sea. The slower the flow or current of a river, the smaller must be the particles of any kind that can be carried. A current of 300 yards per hour suffices to carry particles of clayey mud. This is the ordinary rate of current of a river like the Great Ouse. Twice this rate of current will carry fine sand. One mile per hour would be required to carry particles of gravel the size of a pea. Two miles an hour would roll along the bed stones as big as hen's eggs.*

Deposition.—In the upper course of a river where erosion is greater than deposition the bed is deepened. That is, the work of denudation is vertical. In the lower course deposition is greater than erosion because of the checked velocity of the current. Here the bed is not deepened, but there is a lateral denudation of the banks.

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* The rate of current depends mainly of course upon the angle of the slope down which the river flows. A river with a slope of 1 in 2,600 (about 2 feet to the mile) is navigable with difficulty. The Volga has an average fall of 1 in 21,000 (about 3 inches to the mile).

Deposition begins in the lower course of a river as soon as ever the river begins to move along the almost level plain bordering the sea; where the river meets the sea the remainder of the load is deposited. This part of the river is called the **mouth,** and here, if the sediment is not swept away by currents, the accumulated detritus, called **alluvium** or alluvial deposit, forms a **delta.** During flood-times the lower course of a river often overflows its banks, and when the flood-waters subside by sinking into the earth, the load held by the flood-waters is left deposited on the lately flooded fields. This takes place on a large scale in the lower valley of the Nile. In the lower course of those rivers that are subject to floods, the level tract upon which the flood-waters lie is called the **flood-plain** or flood-area. In the upper course where the current is fastest, the tendency of the river is to flow straightest; in the lower course where the current is slowest, the tendency of the river is to swing from side to side, forming bends and curves. These bends are called meanders, and the serpentine method of flow is called **meandering.*** The River Forth affords a good instance of this. From Stirling to Alloa the distance in a straight line is only 5¾ miles; but the snake-like windings of the river through the Links † of Forth measure 12½ miles. The Mississippi in its lower course also exhibits meanders. The flatter the flood-plain the greater is the arc of the meander. As the river meanders through the flood-plain during flood-

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* So called from the name of a river in Asia Minor, the Menderes —anciently the Mæander, whose windings are after all nothing remarkable.

† The word "links" is a Scotch word meaning simply flat or slightly undulating ground near the seashore or a river. Originally the term has nothing to do with the game of golf, and there are links in Scotland where golf is never played.

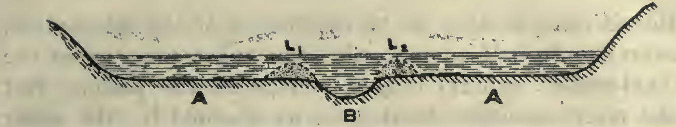

FIG. 104.

time, the waters at *A* (fig. 104) have little velocity, the river at *B* has a much greater velocity. At L_1 and L_2 the velocity of the bed-stream is slightly checked on both sides by the slower flood-water. Hence the banks of the river become raised at L_1 and L_2 by some of the load being deposited there. These raised banks are called *levees*. The lower valley of the Mississippi, though of unsurpassed fertility, was until comparatively recent times left almost uncultivated owing to the dangers of the annual flooding. But nearly 2,000 miles of artificial levees now protect the lands. These were built by the Government in imitation of the natural levees which were found to be insufficient to stem the extraordinary flooding that occurred every year. A flood-plain is really a wide, flat valley through which any river meanders, the high land bounding the valley marking the limit of the lateral spread of the flood-water.

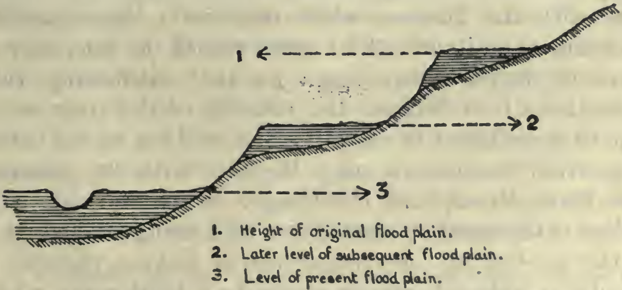
1
2
3
1. Height of original flood plain.
2. Later level of subsequent flood plain.
3. Level of present flood plain.

FIG. 105.—The height of one flood-plain above the other is exaggerated.

But if each flood adds to the height of the flood-plain, even if only half an inch, the time must come when the flood-waters can no longer overspread the plain. But the river continues to deepen its channel by the scour of its loaded waters, and soon even flood-waters cannot reach the original height. So floods now cut into the old alluvium and form a new flood-plain at a lower level. In this way the river-valley comes to show a series of terraces formed of alluvium known as **river-terraces.** If No. 3 (fig. 105) represents a present level, No. 1 must be many thousands of years old, and it is in such ancient formations as these river-terraces that remains of prehistoric man are often found.

Deltas.—The most favourable position for the deposit of river sediment is where the stream encounters a different body of water, *e.g.* a sea, ocean, or lake which checks the river's flow. All rivers, on entering the sea, do not form deltas. Sometimes this is because the river does not bring down sufficient load for the purpose, as is the case with many Scotch rivers flowing through granite beds. Sometimes it is because the sediment brought down is swept away by ocean currents or tidal currents, as is the case with the Thames, which deposits a large quantity of sediment in its mouth at every rise of the tide, only to have it cleared away again by the out-flowing tide. Sometimes it is because the velocity of the river at its mouth is sufficient to carry its load well out to sea before deposition commences, as is the case with the Amazon, the Plate River, and the Congo. Rapid formation of deltas is favoured by a steady or by a rising sea-bed; but if the sea-bed at the river-mouth is sinking, the valley-mouth is widened, giving access to a tidal wave which will prevent delta formation. Estuaries are examples of such submerged river-mouths. In an estuary the forcing back of the river-water by each rise of the tide will cause deposition of sediment in the form of a line across the course of the river. This is known as a **bar.** The Norfolk Broads are estuaries shut in by bars and are silting up from the inside. In nearly tideless seas such as the Gulf of Mexico or the Mediterranean the delta not only fills up the river-mouth, but actually pushes its way into the sea. The Mississippi long ago filled up the bay where its deposits first began, and now pushes tongues of alluvial land far into the Gulf of Mexico. The most typical form of delta is that of the Nile or of the Ganges. The shape of these is almost the triangle from which the formation takes its name (Greek Δ, delta). The delta of the Mississippi is shaped rather like a duck's foot at the end of a very fat leg. But whatever the shape of the **base** or outward boundary of the delta, the point up the river where in ages gone by the mud-laden waters first met the sea is called the **head.** Cairo at the head of the Nile Delta is 85 miles from the base, the head of the Ganges Delta is 200 miles from the base, and Adria (on the delta of the Po), which gave its name to the Adriatic, is now many miles inland. The different arms which form the Delta are known as **distributaries.** The Nile Delta is a well-cultivated, rich alluvial plain, intersected by the natural channels of the distributaries and the artificial irrigation canals, with here and there villages perched upon mounds where clumps of palm-trees grow.* What is called Lower Egypt consists of the delta only, the strip of land along the Nile between the delta and the second cataract being what is called Upper Egypt. The Ganges Delta, in the formation of which the Brahmaputra has taken part, is a district several thousand square miles in extent (nearly as large as Ireland) called the Sunderbunds. The whole district is covered with swampy malarial jungle, infested by wild animals and venomous reptiles. The deltas of the Godavery, the Mahanady, and the Cauvery are, like the Nile Delta, intersected by a network of irrigation canals, and produce immense crops of rice. The most favourable conditions for delta formation are found in lakes where there are no tides and only moderate waves. The lake indeed acts as a filter, removing from the streams, as they flow through, all their load of sediment, and depositing it on the lake-floor. Such a delta is called a **lacustrine delta.** A good example is the fan-shaped delta in Lake Geneva, where the Rhone enters. An ancient Roman town, Port Valais, once on the shore of the lake, is now nearly a mile inland, so that during the last 2,000 years all the alluvial tract between the port and the lake must have been deposited.

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* From calculations made at Memphis it has been estimated that the Nile must have taken at least thirteen or fourteen thousand years to construct the wedge-shaped mass of land, which now forms the Nile Delta plain.

A similar phenomenon is also observable in hill-lakes which have a burn or brook flowing into them. At the mouth of the burn the water is very shallow, and remains so or gently shelving for several yards out into the lake, till the depth suddenly increases and the shelf goes almost sheer down. It is at this point that the brook has deposited all its load. Fishing and wading in a lake off the mouth of such a stream is for this reason very dangerous, as the drop of the bed comes very abruptly.

River-valleys.—The oldest part of a river-course is the mouth, that being naturally the first developed. The head waters in the upper course are always cutting their way backwards (see p. 413), and consequently these are the newest parts of both the main stream and the tributary streams. While the upper course is new and has not suffered much weathering, the head-water valleys are U-shaped, that is, narrow and gorge-like, and in the lower course V-shaped, that is, more broadened out at the top by weathering. In other words, the younger a valley is, the more will erosion exceed weathering, while the older a valley is, the more will weathering exceed erosion. In rainless regions, where no weathering occurs and erosion downwards is the only form of denudation at work, deep vertical gorges called cañons are cut by the rivers, *e.g.* the Grand Cañon of Colorado. So sheer are the nearly perpendicular walls of the cañons that it used to be thought they were great rents in the earth into which the rivers had found their way. Careful observation, however, goes to show that they are the same thing on a large scale as the gullies that occur in any mountain streamlet. " The water has laid hold of some line of weakness in the rocks and worn out its channel energetically along it" (Cole). The cañon of the Colorado is the longest and the deepest in the world ; it is 300 miles long and in places its walls are 6,000 feet high. Other rivers on the same slope, such as the Fraser and the Columbia, have carved for themselves similar deep, vertical gorges. If rain fell in such regions, or if many tributaries broke through the banks of the main stream, the sides of the cañon could not retain their position as vertical walls. They would then be weathered into sloping sides like any ordinary river-valley. In early Victorian days it was believed that valleys existed first as crust-wrinkles, that rivers flowed into the valleys, and then followed the course allowed to them. But this is only partly true. It is true in the case of the longitudinal valleys (see p. 334) that lie between folded ranges such as the Bernese Oberland and the Pennine Range in the Alps. Through such a valley flow the upper courses of the Rhine and the Rhone. It is true also of rift-valleys. Such a valley is found in the middle course of the Rhine where a strip of crust 20 miles broad and 200 miles long has sunk between two parallel cracks or faults. The Jordan also flows through a rift-valley. In East Africa is a rift-valley extending from Lake Tanganyika to Lake Albert, in the floor of which are cross faults which give rise to transverse ridges higher than the more sunken parts. In the deepest hollows are lakes. But it is not true of the transverse valleys that cut through ridges by the backward erosion of river-heads, nor is it true of young rivers flowing down recently uplifted slopes (see footnote p. 413). When a surface formerly level undergoes tilting or folding, the young rivers as a rule follow the lie of the new slopes. Soon they proceed to deepen their channels, if the slope be great enough to give them an active current. These channels will in time become main valleys with subsidiary or transverse valleys cut down to them by subsequent streams. In all valleys of erosion the torrential head-waters of the streams rush down a narrow gorge, and in time cut their way back farther and farther into the hills, until the former gorge has become the broadened valley of the stream's middle course.

Oxbows.—In the flood-plain where the river meanders leisurely, there is always in progress the work of augmenting the meanders. It will be seen by referring to fig. 106 that the current always works more on the concave bank than on the convex. As a result of this the concave bank becomes undercut and always shows a steeper side than the convex bank; whereas the convex bank receives the deposit of the slower waters. Fig. 107 shows what a strongly curved meander becomes with only a narrow neck to be cut through to form a new channel. When the neck is broken through, the

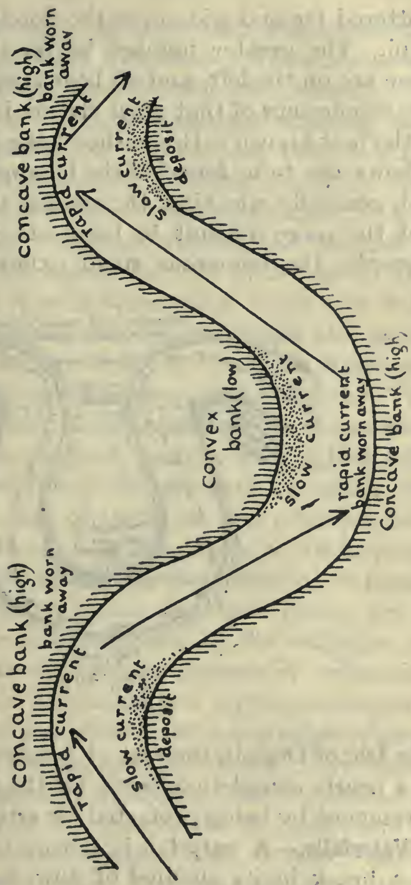

FIG. 106.

old meander remains as an abandoned portion of the old river-bed. This is called an **oxbow,** or cut-off, and if filled with water, a **mortlake.** An oxbow generally becomes filled up by sediment when the stream is in flood. In Nottinghamshire, at Bole on the Trent, there were formerly two big loops of the river with narrow necks opening into Lincolnshire. The land thus nearly surrounded by water naturally belonged to that county. In 1797 the river assumed its present course across the necks of these loops, leaving the old curves and the Lincolnshire fields in Nottinghamshire. It is said that the final breaking down of the neck at Bole Round was helped by a bargeman ramming it with his barge. Many large crescent-shaped lakes, formed from oxbows, are scattered far and wide over the flood-plain of the Mississippi. The greater number lie on the right bank, but some are on the left, and all bear testimony to the extensive wanderings of that great stream in former ages. One of the best known is Horse-shoe Lake in Arkansas. Small oxbows are to be found in the flood-plains of most rivers, and, generally speaking, the smaller the river the smaller and the more difficult to trace are the oxbows, as, for example, the numerous small oxbows of South Wales.

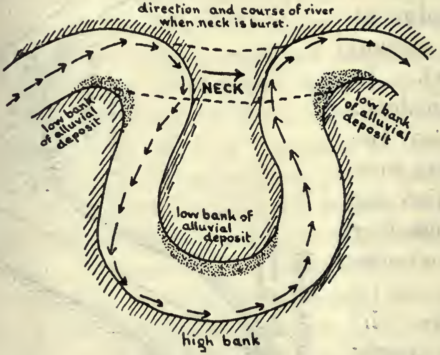
direction and course of river when neck is burst.
NECK
low bank of alluvial deposit
low bank of alluvial deposit
low bank of alluvial deposit
high bank

Fig. 107.

The Isle of Dogs in the east of London is a good example of a nearly complete oxbow; for the neck has been made permanent by being protected by artificial embankments.

Waterfalls.—A waterfall is a body of water that, owing to a break in its channel of flow, makes a more or less vertical descent. They are also called cascades and cataracts. They occur most frequently in mountainous countries. Here the configuration of the land is such that long and deep river-valleys have tributary streams whose harder beds have not been eroded down to the level of the main stream. In such cases the tributaries enter the main stream over waterfalls. These mountain waterfalls change their aspect with the seasons. In winter the water pours over and plunges headlong as a torrent into the depths below; in summer there is often no more than a mere film of water trickling down the face of the precipice. On a stream running into Loch Ness in Inverness are the two Falls of Foyers, the highest in Great Britain, with an aggregate drop of 205 feet. The Sutherland Falls in New Zealand drop 1,904 feet with three leaps; the Yosemite Falls in California also make three plunges in a descent of 2,660 feet, and the Kukenam Falls in Guiana make a sheer drop of 1,500 feet. The Roraima Falls in British Guiana fall from a stupendous cliff 7,000 feet above sea-level, and are the highest falls in the world. In relatively flat districts waterfalls are not so common, yet some of the finest and grandest falls of the world, such as the Falls of Niagara in North America and the Victoria Falls of the Zambesi, are to be found in comparatively level regions. In these flatter areas the fall of the water is usually due to the existence in the river-bed of rocks of differing powers of resistance to erosion, lying either horizontally or dipping up-stream (see p. 414). In these waterfalls there is a greater volume of water than in the mountain type, that is, they make up in breadth what they lack in height. There is a steady, even flow of the river to the head of the precipice, and a thundering plunge of the mighty wall of water as it descends to the lower level. The Niagara Falls, only 170 feet high, are due to a resistant layer of compact limestone 90 feet thick covering layers of more easily eroded soft shales. The bed of soft shales is being continually undermined by spray, wind-blown water, and frost, leaving the limestone proejcting until it can no longer remain unsupported. This work of backward waste is continuous, and conjectures put the rate of average recession at a foot per year. The falls probably began at the escarpment called the Heights of Queenstown, 7 miles from the present falls. Therefore at least 35,000 years must have been occupied in cutting back to the present position.

Utility of Waterfalls.—A long fault-line cutting transversely the beds of many streams may cause waterfalls in every stream it crosses. An example of such a line of falls exists just inland from the east coast of the United States, and in most cases a town has grown up at the falls—primarily because the fall marked the head of navigation—and has grown in importance because of the additional advantage of water-power procured from the falls. Such towns are Philadelphia, Baltimore, and Washington. A similar fall-line is to be found both north and south of the Amazon. Waterfalls, besides being breathlessly beautiful and awe-inspiring, have an industrial value. They may supply energy either directly by turning a wheel or a turbine, or indirectly through the electricity generated in dynamos worked by turbines. From the dynamos the electric current at a high potential may be transmitted by wires to distant stations and there transformed into a current at a lower potential for lighting, heating, or driving a motor and keeping a whole factory in operation. A very common industry carried on by electrical processes at or near waterfalls is the extraction of aluminium from bauxite (a hydrate) and cryolite (a fluoride containing sodium). Such work is done at Neuhausen, near the Schaffhausen Falls of the Rhine; the Niagara Falls are used in the same way. For the aluminium smelting done at Foyers and at Kinlochleven, material is brought from the north of Ireland; but at the latter place the power is obtained by an artificial fall. Flour-mills are driven by power from the St. Anthony Falls at Minneapolis and at St. Paul. The cities of Buffalo and Toronto are lighted by electricity generated at Niagara; the Shawinigan Falls on the St. Maurice River in Quebec supply Montreal with electrical current; Ottawa obtains its electricity from the Chaudière Falls in the very heart of the city; and it has been proposed to convey electricity to the Transvaal goldfields from the Victoria Falls on the Zambesi.

River Capture.—In the development of a many-branched river system, there was one stream among the many that was the first to flow down the original slope. This is known as a **consequent** stream, which is nearly always

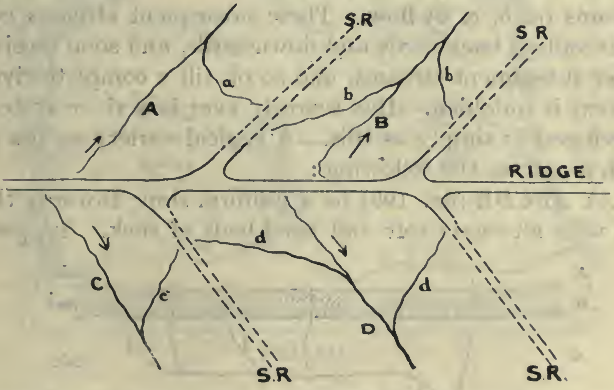

Fig. 108.

(though not necessarily) the same thing as the main stream. Tributaries enter the main stream subsequently, and are therefore known as **subsequent** streams. The simplest form of river development is shown in fig. 108. From the central ridge down both slopes flow the consequent streams *A*, *B*, *C*, and *D*. As these streams deepen their

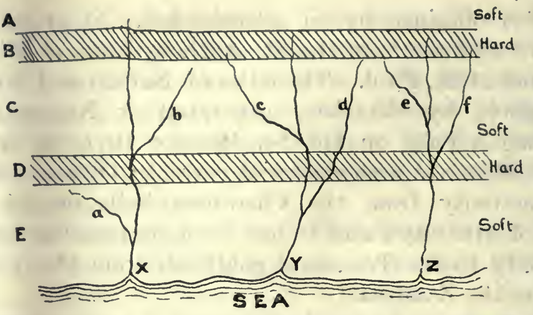

FIG. 109.

valleys, the high ground between their courses takes the form of secondary ridges (*SR*) down which subsequent streams (*a*, *b*, *c*, *d*) flow. These subsequent streams cut their valleys backwards and downwards, and soon receive other subsequent streams, and so on till a complete river system is unfolded. But scarcely ever is a river system developed as simply as this. A typical variety occurs in such a case as the following:

Let *ABCDE* (fig. 109) be a uniform slope towards the sea with alternate soft and hard beds of rock. Suppose

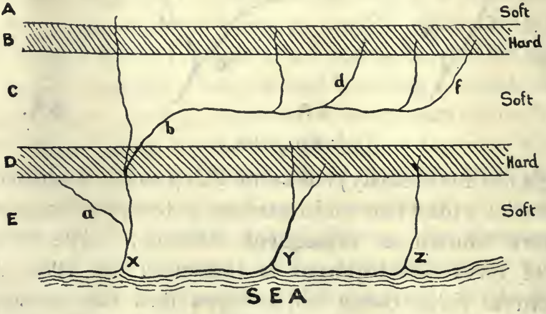

FIG. 110.

the slope just lifted up from the sea and therefore almost at a dead level. Consequent streams would flow to the sea at *X*, *Y*, and *Z*. As these streams deepened their valleys, subsequent streams would flow in at *a*, *b*, *c*, *d*, *e*, and *f*. Now suppose the valley of *X* deepened more than those of *Y* and *Z*. *X* would then have a greater volume of water and

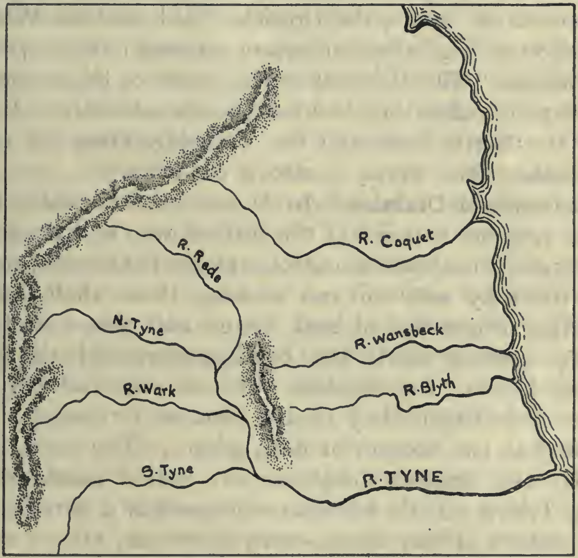

Fig. 111.

be swifter. Its subsequent *b* would cut its way back and draw off the waters of *c*, and later of *Y*, and so on, until all the water flowing down the ridge *BC* was caught and drawn off by the stronger stream *b* into *X*. The subsequent is then said to have *cut off the heads* of, or *captured*, the other rivers. When this stage is reached the plan of the rivers on the slope will be as in fig. 110.

This process of river-capture is going on, or has been going on, in most river-basins. A very good example is to be found in Northumberland. The arrangement of the rivers in the diagram (fig. 111) is self-explanatory.

A further example is the Yorkshire Ouse. The Humber is a direct continuation of the Aire and Calder. The Ouse is a subsequent stream that has captured the head-waters of the Swale, the Ure, the Nidd, and the Wharfe, which were originally consequent streams flowing straight to the sea. The Derwent is the result of the remaining consequents after they had lost their head-waters. Rivers like the North Tyne and the Yorkshire Ouse are called **cut-backs.** The Trent is also a cut-back.

Underground Drainage.—In those districts where limestone rock lies exposed at the surface, rain and streams in many cases disappear along joint-planes in the rock, enlarging them by solution and making them shaft-like by whirling fragments of rock round and round in them. Then, working along the bedding-planes of the limestone blocks, the streams eat out subterranean passages from which they finally issue as torrential rivers, flowing at the bottom of deep gorges. The holes down which the streams disappear are called **swallow-holes.** Near Trieste on the Austrian sea-board is a bare, desert-like district of this stream-worn limestone, known as the Karst, and this name is often used to describe similar landscapes elsewhere. Swallow-holes are common in the West Yorkshire Pennines, many of them being several hundred yards in diameter and often leading down into underground caverns. Those of the Blue John mine, the Speedwell mine, and the Peak Cavern, near Castleton in the Peak district of Derbyshire, are examples of caverns formed by dissolution and erosion. Bradwell and Eyam, quite close by, have some fine though very little known caves. Sometimes the stratum overlying an underground cavern or river gives way, and falls, forming in a short space of time a deep gorge, like the famous Cheddar Gorge. Five miles north of Kilkenny in South-east Ireland are the remarkable caves of Dunmore with their spacious central chamber entered through an archway from 60 to 100 feet high. In Kentucky, U.S.A., the streams have cut many deep gorges and caverns. The swallow-holes here are called "sinks." The extensive caverns form a remarkable physical feature of this state. The best known, and perhaps the largest in the world, is the Mammoth Cave, 10 miles in diameter, and containing over 150 miles of winding passages connecting the many chambers. There are several lakes and rivers within the cavern all connected with the Green River, a tributary of the Ohio. Animal life is confined to a few species of fish, some insects, and bats. The fish, the product of successive generations in the dark, are blind from the egg.

Rivers as Highways.—That rivers have a great use and interest for man is amply indicated by the fact that all the most important cities of the world have been built upon their banks. This selection of a river-site was seldom, if ever, due to the picturesqueness of the scenery, but rather to the utility of the water to the settlers. In our own country, in the eighth century, the Danes used the rivers as a means of facilitating their conquest of the Anglo-Saxon tribes and afterwards made settlements along the banks. Every town built upon the banks of a river has water-communication two ways; towns placed at the confluence of two streams have water-communication three ways. Before the advent of railways, exchange of goods between town and town throughout the country was made possible by rivers and the canals which linked them up. Except for about fourteen miles of porterage, the rivers of Siberia make it possible to send goods from the Urals to Lake Baikal. Canada also is able to profit by her excellent river systems. By means of the St. Lawrence and its canals, goods may be transported from Port Arthur on Lake Superior to Montreal, or by the Erie Canal and Hudson River to New York. Or again, boats can carry their loads from Hudson Bay to Calgary via the Nelson River, Lake Winnipeg, and the Saskatchewan.

The river system of Central Europe has been highly developed. By means of the Ludwig Canal, which connects the Altmühl (a tributary of the Main) with the Regnitz (a tributary of the Danube), a complete waterway from the Black Sea to the North Sea is secured via the Rivers Danube and Rhine. The Rhine, in its turn, is likewise linked up by the Rhine and Marne and Rhine and Rhone canals with the Seine and Rhone.

Rivers and Cultivation.—Rivers render service to man as surface-drainage systems. They are sometimes made to act as sewers, but this should not be their use in a scientific age. In countries like Egypt, subject to long droughts, a river is the very life of the country; for cultivation can be successful only within reach of its water. Since early times, by means of water-wheels, and by leathern basins called *shadufs*, water has been raised from the Nile and used to irrigate small portions of country at all times of the year. For irrigating large areas the flood-waters used to be led off from the river to the fields by long canals during the flood-season (July, August, and September), and then were allowed to drain back to the river after saturating the ground and depositing their load of fertile silt. But this meant barren land after the winter crop had been harvested, until the next autumn flood. Now, barrages have been built at the head of the Delta, at Siut, and at Assouan, and these hold back the waters to be used as required.* The fly in the ointment lies in the fact that when the dammed-up waters are led off from the reservoirs over the land they leave their mud in the reservoirs, and the fields must be manured as a separate operation. The Po and the Hoang-Ho are examples of rivers that, flowing above the level of the surrounding district, may be tapped by the natives to provide irrigation for parts of their basins.

Rivers as Boundaries and Water-suppliers.—Rivers make excellent and unmistakable natural boundaries between either parish and parish or country and country, except in those cases where the lower river is constantly changing its course. They also provide a supply of drinking-water for large cities. London obtains most of its water from the Thames and its tributaries; for Birmingham's needs the River Elan, a tributary of the Wye, is banked up and made into a reservoir (the Cwm Elan); Lake Vyrnwy, the natural reservoir of the river of the same name, supplies Liverpool; Thirlmere supplies Manchester, Loch Katrine supplies Glasgow, the Vartry supplies Dublin, the Trent supplies Gainsborough, and so on.

Various Dangers and Uses of Rivers.—Rivers, however, good servants though they be, can also be bad masters. Serious or dangerous flooding does not usually occur in those rivers that pass through many lakes, for the lakes, acting as natural reservoirs, check the violence of their flow; but other rivers often work terrible havoc during flood-seasons. The Yellow River in China, on account of its devastating floods, has been called "China's Millions of Sorrow." Millions of lives were lost in 1887 by the flooding of the Shantung Peninsula by this river. In the United States flood predictions are now regularly issued for several of the principal rivers. Tidal rivers allow navigation to proceed further up from the sea than would be possible without the tides. Ocean liners are able, by taking advantage of the tides, to reach Tilbury on the Thames, and other vessels can make use of the tides as far up as Teddington, seventy miles from the sea.

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* The rise of the Nile waters, before the construction of the barrages, was recorded by the Nilometer built by the Khalif Mutawakhul more than ten centuries ago, on the island of Roda, opposite Cairo. A square well, from the water of which rises a marble column, is connected with the river by a canal. As the river rose, more and more of the pillar was hidden. The reaching of the 18 cubit (cubit = 20 inches) mark meant the vanishing of the starvation spectre, 22 cubits meant complete satisfaction. But passing the 24-cubit mark meant devastation. Before the building of the Nilometer, flood-registers were accurately kept as far back as 3600 B.C., so that the Nile barrages may well be said to have mitigated the anxiety of 5,000 years.

Benefit of River-plains to Man.—So many are the advantages, commercial, agricultural, industrial, and salubrious, of the lowlands through which rivers flow, that the broad river-valleys of the world have always been considered the most attractive sites for human settlement. Every shower of rain, as well as the river-floods, brings down from the highlands new soil to enrich the lower land in the valleys, so that valleys are floored with deep and fertile soil, as for example the valleys of the Ganges and the Po. Movement is difficult across mountains; in the broad flat valleys it is easy. Hence main roads and railways, because of the easy gradients, usually follow the valleys. The mountains or hills bordering the valleys also afford considerable protection to the valleys from inclement weather. The valleys of the Ganges and the Po again are good examples. The climate of the Trans-Himalayan uplands with its northern aspect is in striking contrast to that of the Ganges Valley with its sunwards aspect. In our own island until the beginning of the eighteenth century the superior conditions of life in valleys and plains was well illustrated by the difference between the Highlands and the Lowlands of Scotland.

Exercises

1. Draw a sketch-map of the railway from Vienna to Constantinople, and explain why the railway follows that course. Why is part of the route known as the "diagonal furrow"?
2. Why is irrigation so necessary in Egypt, Persia, and Italy?
3. Why are systems of internal drainage usually found in connection with plateaux?
4. What is a delta? Why are deltas so common in the Mediterranean?
5. Distinguish between salt water, fresh water, pure water, hard water, and soft water.
6. What is meant by the *average fall* of a river-bed?
7. What is meant by the statement that "Holland is the waste of Switzerland"?
8. How can the amount of material in solution carried down by a river in a year be determined? (see p. 442).
9. Many of the great rivers of the world are in flood at certain seasons of the year.

   Give one example of each of the chief ways in which this flooding takes place. State the season (or seasons) at which it occurs in each case, and account for the facts. (Oxf. Sen. Loc.)
10. Describe fully the characteristics of a region of inland drainage, and give two examples of such regions. (Oxf. Sen. Loc.)

11. Contrast the character of the river-mouths in southern and western Europe. Explain the differences and show how sites of ports and commercial facilities are affected.

12. Describe the gradual formation and present characteristics, physical and industrial, of any one alluvial plain in the British Isles.

13. Explain the meaning of the terms *flood-plain* and *river-delta*. How are these formed, and what are their special characteristics? Give examples. (Oxf. and Camb. Lower Cert.)

14. Important ports are generally some distance from the open sea, on the estuary of some river. Explain why this is so. (Oxf. and Camb. Sch. Cert.)

15. (*a*) Why does the Ganges rise from May to September?
    (*b*) Why does the Rhone enter the Lake of Geneva as a swift and turbid stream and leave it clear and transparent?
    (*c*) How is it that deltas are common at the mouths of rivers falling into the Mediterranean, and that large rivers in South America form no deltas?

16. Describe with examples the action of rivers (*a*) in forming new land, (*b*) in shaping the general surface of the country. (Oxf. Jun. Loc.)

17. Describe a typical delta. Point out and explain the differences (*a*) in the time of flooding, (*b*) in the usefulness of the deltas on the following rivers: Nile, Niger, Mackenzie. (Oxf. and Camb. Sch. Cert.)

18. What is meant by the basin or drainage area of a river? Compare the regions drained by rivers flowing to the Atlantic with the regions drained by rivers flowing to the Pacific (i) in size, (ii) in economic importance. (Oxf. and Camb. Lower Cert.)

19. Explain the meaning of the terms *longitudinal valley, transverse valley, col.* Give one example of each.

    Why is the arrangement of transverse valleys and cols specially important in determining the positions of roads or railways in a mountainous region? (Oxf. Jun. Loc.)

20. Compare the advantages and disadvantages of rivers as political frontiers. Give examples. (Oxf. Jun. Loc.)

21. In some drainage areas the upper streams flow into a lake which is drained by the main river into the sea. What are the chief effects of the existence of the lake on the area? Give examples. (Oxf. Sen. Loc.)

22. What is a water-parting?

    Give (*a*) an example of a water-parting which is very clearly marked, and (*b*) an example of an ill-defined water-parting. Draw sketch-maps illustrating your examples. (Oxf. Jun. Loc.)

23. Compare the characteristic features of the river systems in regions where the surface consists of (*a*) clay and (*b*) limestone. Account for the differences. Give examples of each type and region. (Oxf. Sen. Loc.)

24. What is meant by the *delta* of a river and how is it formed? Give an example of an important river which forms a delta and of one which does not, and explain the reasons for the difference.

    Why are river-deltas usually thickly populated? (Oxf. Jun. Loc.)

25. Explain what is meant by the expressions water-parting, river-basin, delta. Upon what conditions does the navigability of a river depend?

26. Explain the following geographical facts:

    (*a*) The Nile overflows its banks at approximately the same period every year.

    (*b*) On the right bank of the Volga there are high cliffs, while the left bank is, in general, low. (Oxf. Loc. Sen.)

    [According to Ferrel's law, rivers in the northern hemisphere tend to erode their right banks more than their left banks (see also p. 422).]

27. Describe carefully how rivers act (i) as *denuding* agents, (ii) as *depositing* agents. Illustrate your answer by reference to some *one* continent whose geography is known to you. (Coll. of Preceptors.)
28. What natural conditions lessen the value of rivers to man? Show how some of these conditions may be artificially improved. In every case give a particular example drawn from some great river. (Civil Service.)
29. What is a water-parting? Show by means of a map how the Alps determine the courses of the rivers of S.E. France, W. Germany, and N. Italy. (Oxf. Jun. Loc.)
30. If the bed of a river is made of rounded pebbles, how did they get there, and how is it that they are rounded? (Coll. of Preceptors.)
31. Describe the effects produced by a river (*a*) in the upper and steeper part of the course, (*b*) in the lower and flatter part of the course. (Civil Service.)

EXPERIMENTS ON MUD AND RIVER-VELOCITY

Analysis of Mud.—(*a*) You may analyse the mud found on a river's banks as follows: Obtain a small quantity of it and allow it to dry. Then weigh and place it in a beaker, and pour over it some weak acid. Stir the mixture well so as to allow the acid to dissolve the limey or calcareous part from the mud. Now filter the mixture and weigh the residue of mud thus obtained. The amount of lime or chalk that was originally in the mud equals the difference between the first and second weighings. Put the filtered mud back into another beaker that contains water, and stir up well, afterwards allowing the mixture to settle for a few minutes. While the finer particles are still in suspension, pour off the water, leaving the larger particles at the bottom of the beaker. Perform this operation twice, and so separate the clay from the sand. Weigh the sand that remains in the beaker, and so arrive at the percentage the sand bears to the whole amount of mud. In this way you will have analysed mud into its three chief constituents: (i) calcareous matter, (ii) sand, (iii) clay.

(*b*) To determine the amount of solids in river-water: Take two samples of the same river-water. Filter the first sample, and so test for matter in suspension. Then evaporate to dryness the second sample, and so test for the *quantity* of matter in solution. In the latter case the water should be weighed before the experiment; then the solid matter left after evaporation has ceased should be next weighed. The percentage of matter in solution

$$= \frac{\text{weight of dry solid} \times 100}{\text{weight of water}}$$

Velocity of Flow.—(*a*) To show that the greater the velocity of the flow of a river, the greater are the particles that can be carried by it. Procure two test-tubes, *A* and *B*, of different sizes, and a gas-jar, *C*. In *A* place ½ inch of ordinary soil and connect up the

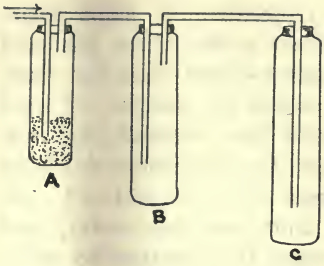

FIG. 112.

vessels by glass tubing, as seen in diagram (fig. 112). Attach with a piece of rubber tubing the glass tube leading from *A* to a water-tap and turn on the water to flow in the direction of the arrow. Where the width of the vessels is least, the velocity of the water is greatest; it pours into tube *A* faster than it enters tube *B*, and enters the jar *C* slowest of all. When the water is observed to have risen up well in *C*, turn off the tap, and examine the material left in each vessel. You will find that *coarse* particles are left in *A* where the velocity of the water has been greatest; *medium* have been carried to *B*; and the *finest* to *C*, where the velocity of the water has been least of all.

(*b*) A river flows faster in the middle than at its sides, because the water there is not checked in the same way as it is near the edges by the banks. To show that this is so, set up two poles *A* and *B* about 50 yards apart along the bank of a river, and place three small blocks of wood of the same size in the river just above the pole *A*—one a few yards distant from the right bank, another a few yards away from the left bank, and the third in the middle of the river. Note the respective times taken for each block to reach in line with the pole *B*. You will find that the block in mid-river covers the distance in the shortest time, which proves that the velocity of the river is greatest in the middle.

The surface water of a river has a greater velocity than the water near the river-bed for the same reason as that given above, viz. it suffers retardation in a lesser degree because it is farther away from the bed that offers the resistance to the flow. To prove that this is the case, weight a stick so that it stands up in water. Throw it into the river so that it takes up this position:

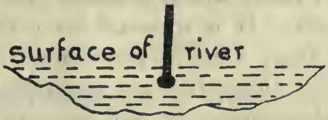

FIG. 113A.

Presently it will assume another form, like this:

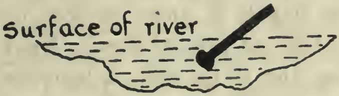

FIG. 113B.

The change from a vertical to a slanting position is due to the surface water having a greater velocity than the water underneath. Flowing at a faster rate, it tries to carry the upper part of the stick with it, but is prevented from so doing by the slower movement of the under part of the stick. Hence the slanting form.

(*c*) The **rate of flow** of a river is calculated in the following way: Obtain a small block of wood to act as a float, and choose a reach of a river where the course is fairly straight. Erect, as in the former experiment, two poles *A* and *B* 50 yards apart along the bank of the river. Throw the float into the river a few yards distant from the near bank above *A*, and time with a stop-watch how long it takes to pass from pole *A* to pole *B* without interference. Next, time it for the same distance in the middle of the river, and lastly for a point a few yards away from the farther bank. The average of these times gives the average time of flow of the river for a distance of 50 yards. Suppose the times thus obtained to be 75, 80, and 70 seconds respectively—an average of 50 yards in 75 seconds. This works out at a rate of flow of $1\frac{4}{11}$ miles per hour, which is about the rate of flow of an ordinary river. It is unusual for a river to flow at a greater rate than 4 miles per hour. Rivers flowing at a greater rate than that are unnavigable, extremely destructive in their character, and are capable of carrying stones weighing almost a hundredweight with them.

(*d*) The **amount of matter** brought down by a river may be found as follows: Choose any section of the river where the depth is more or less uniform, and at that point calculate its rate of flow. Next make a set of soundings across the river with a lead-line (see p. 293). Take an average of these soundings and so determine the mean depth of the river. The amount of solid matter in suspension per gallon may be obtained by the method previously explained (see p. 439).

The area of the section of river = mean depth × breadth of river.

The volume of water carried down by the river in a day

$$= \frac{24 \times \text{rate of flow (in ft. per hour)} \times \text{area of sect. (in sq. ft.)} \times 10}{1000} \text{ gal.}$$

since 1,000 cubic feet contain 10 gallons of water.

The number of gallons of water carried down per diem being thus found, it only remains to multiply the result by the number of grains of matter held in solution per gallon to obtain the amount of matter that passes down with the river at any point.

CHAPTER XXIX

Lakes

Definition and Classification.—When water flows into and accumulates in a depression on the earth's surface a lake is formed. But though a lake might be defined as an inland body of water accumulated in a surface depression, the term or the word lough is sometimes applied to the widened parts of rivers, and sometimes even to bodies of water which lie along coasts and have direct connection with the sea. Lakes may be classified and studied in two distinct ways—geologically and geographically. The geological classification is concerned with the mode of formation of the basin or depression; the geographical classification is concerned with the mode of entrance or exit of the water from the lake. The geological classification considers :

1. Basins scooped out of solid rock.
2. Basins formed by a glacier dam.
3. Basins in folded tablelands; or subsidences in a plain.
4. Basins in volcanic craters.
5. Basins enclosed by a sand-bar on a low sandy coast.

The geographical view-point classifies lakes as under :

1. Lakes with inlet and outlet.
2. Lakes with inlet and no outlet.
3. Lakes with no inlet but with an outlet.
4. Lakes with neither inlet nor outlet.

Lakes (besides their supply from rain-showers) receive their water in several ways, the most important of these being (*a*) from tributary streams (rivers), (*b*) from glaciers, (*c*) from springs in the basin. The presence of lakes may be generally taken to indicate a "young" drainage system—that is, one in which the land surface has been recently folded or tilted, not one in which the rivers have carved out a valley or trough for themselves as distinct from the lakes which may form part of their course. A lake is really only an ephemeral feature in the life of the river system to which it belongs. An inflowing river may silt it up; an outflowing river may deepen and widen its outlet and so drain the whole lake away; but, though the lake disappears, the river often remains. Many of the Scottish plains or straths have been so formed, the lakes giving place to marshes which in turn have become fertile plains.

Formation of Lakes.—Lakes owe their origin to many causes. Sometimes an accumulation of matter is thrown across a river-valley, with the result that the water in the river is dammed up and so forms a natural reservoir or lake. The barrier or obstruction is generally the result of a landslip or of a lava deposit, or is due to glacial action. In the latter case the glacier has traversed the river-basin transversely and deposited moraines *across* the river-valley, and thus prevented the river from flowing onwards. Many examples of lakes which have been formed in this way are to be found in Cumberland and Central Wales. Glaciers have also scooped out basins from the rocks over which they flow, through the grinding and erosive action of their ground moraines. The lakes of Finland and of the Scottish Highlands are good instances of this scooping action of glaciers. An examination of the valleys in the Scottish Highlands provides us with clear evidence of glacial erosion. Many of them are U-shaped in form, having their rocky sides polished and scraped by the lateral moraines which once passed over them. Seismic disturbances have also been active agents in lake formation. The gradual, but constant changes that have taken place, and are still taking place through underground movements of this kind, have played their part in the production of lakes as well as in altering the configuration of the land-surface and the ocean-floor (see p. 321). Rock Lake in Columbia District, U.S.A., was formed by the filling-up of a fissure formed during an earthquake. There is to this lake neither inflowing nor outflowing river, and the water-supply comes from an underground spring. Where subsidence has caused a depression to be formed on the earth's surface, there a lake is almost sure to be formed. In some cases subsidence is due not entirely to seismic disturbances, but to a collapse of the earth's crust from the dissolving power of the water that flows over underground rocks. In limestone districts lakes of this class are very common. Most of the Irish lakes, including the lakes of the central plain, Lough Mask and Lough Neagh, have had their origin in this way. Volcanic craters also form a convenient site for the formation of lakes, which may be fed by underground springs or by rainfall. Lake Avernus near Naples and the famous Crater Lake in Oregon, U.S.A., are examples. The disappearance of the immense ice-sheet which at one period covered northern Europe also assisted in lake formation by causing accumulations of matter to be deposited in irregular quantities on the earth's surface. In Ireland the glacial action of this period is very markedly shown in the absence of any bituminous coal deposits and the many hollows that have been formed on its surface. These hollows have been in time filled with water and are remarkable for their shallowness. Each of these lakes, like the tarns in the Cumbrian Mountains and the lakes of Finland, is surrounded by a bank of gravel which has been deposited by glacial action.

Lakes with Inlet and Outlet.—A very large number of lakes come under this class. Almost all those in Great Britain have rivers flowing into them, with another river to carry off the superfluous water. Such lakes act as filters. In Switzerland, the Rhone comes in at the eastern end of Lake Geneva as a muddy stream; but it leaves the lake as a clear stream, after covering the lake-bottom with a layer of fine silt. This filtering action of lakes may be seen in progress if we examine any lake in our neighbourhood after a heavy rainstorm. The water of the lake—especially that near its shores—may be observed to be much disturbed and discoloured with the sediment carried down by inflowing streams. But at the point * where the superfluous water is being discharged the water presents a fairly clear appearance. It is, therefore, obvious that the sediment of the inflowing river-water has been deposited in the bed of the lake. At the mouths of all inflowing streams a constructive action, in all respects similar to that seen at the mouths of rivers entering the sea, is in progress. A miniature form of delta known as a **lacustrine delta** is thus being formed (see p. 420). The inflowing stream may push the delta out from the shore until it stretches across the lake and so cuts it into two parts. In this way the delta of Sail Beck in Cumberland has cut off Crummock Water from Buttermere. By this process of deposition, any lake will in course of time disappear. In its place will be a fertile alluvial flat over which the stream will wander.

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* A lake may have many inlets, but usually has but one outlet.

Lakes with both inlet and outlet are often nothing more than the expansion of rivers, and their waters are almost wholly fresh. Loughs Ree and Derg are, for instance, mere expansions in the limestone basin of the Shannon. Of course all the so-called fresh water in rivers and lakes contains certain salts in solution. Of these salts the least common is common salt, its percentage of all the matter in solution being but 3. Carbonates of calcium and of magnesium make up more than 50 per cent. In so-called salt water, on the other hand, common salt vastly preponderates over the other substances in solution (see p. 304). As has been stated, glacier action as well as the expansion of rivers has been very active in forming lakes of this class. When the melting-point of a glacier retreats up a valley, it still supplies the water to the hollow basin that has been blocked up by its terminal moraine. The superfluous water is discharged over the barrier so formed. Lake Geneva is an example.

A special type of lake is called a **lagoon.** A lagoon is not a lake in the true sense of the word, since it is generally connected with the sea by a narrow channel. All lagoons * are shallow portions of the sea enclosed by a narrow neck of land, the neck in most cases being composed of sand or shingle. Along the shallow shores of low-lying lands the bottom sands are dashed upon the shore by storms, and in course of time sand-reefs are built up which enclose long and narrow stretches of water generally lying parallel to the shore-line. Though the surface-waves are constantly eating away the reef, yet fresh sand is as constantly brought up from the bottom, and thus the stability of the reef is maintained. Off the north coast of Germany these lagoons are called *haffs*, and the necks of sand which enclose them are known as *nehrungs*. The Gippsland Lakes (off the coast of Victoria, Australia) are almost of identical formation, as also are the "backwaters" of Cochin and Malabar in South-west India. These are a connected series of lagoons strung along the coast with occasional outlets to the sea. To a certain extent—for small craft and rafts—they are important waterways. Most lagoons, *e.g.* the Cochin backwaters, receive drainage from the land, but the salinity of the water inside the lagoon depends upon the width of the channel leading out into the sea. If the channel is small, the water inside the lagoon will be practically fresh water; if large, the water inside will be brackish. The largest haff in the Baltic Sea is the Kurisches Haff (see p. 178). It stretches from Königsberg to Memel; is sixty miles long and about thirty miles wide.

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* This type of lagoon is to be distinguished from the coral-island lagoon, which is generally deeper.

Lakes with Inlet and no Outlet.—Many lakes of this class have possibly in the past formed part of some great inland sea. The Asiatic Depression to the east of the Caucasus contains several lakes of this type. Of these the largest are the Caspian Sea and the Sea of Aral. Since these lakes have no outlet and the level of the water does not rise, the surplus water must go off by evaporation. This is clearly the case with the Caspian Sea, whose waters are shrinking from year to year. Shrinking in such lakes is, therefore, the result of the small amount of rain and river-water they receive in comparison with their great loss through evaporation. For this reason their salinity and consequently their density increases each year. For example, the specific gravity of the Dead Sea water is 1·23, and 1 ounce of water from this sea, carefully evaporated, leaves about $\frac{1}{4}$ ounce of solid matter, of which 25 per cent. is common salt. Lake Van, which contains 33 per cent. of salt, and Lake Tuz Gol in Asiatic Turkey are considered to be the densest bodies of water known. Other very salt lakes are Lake Elton in Russia, and Urumiah in Persia.

Lakes with no Inlet but with Outlet.—There are very few lakes, comparatively speaking, which, without appearing to receive any inflowing streams, send forth a constant flow of water. The surplus water sent forth by the discharging stream and that lost through evaporation are derived in either of two ways: (i) from underground springs in the lake basin or (ii) from subterranean rivers. Lakes of this class are *fresh*-water lakes, and are commonly found in limestone regions in which subterranean channels exist. Lough Mask in Galway is said to be connected with Lough Corrib in this way.

Lakes with neither Outlet nor Inlet.—A very small number of the world's lakes belong to this class. It is clear that although they have no visible inlet they must receive water by some means, otherwise in a short time they would be dried up. In all probability their main supply is derived from underground springs. Moreover, the supply may equal, but does not exceed, that lost by evaporation, for if it exceeded, the surplus water would flow out of the basin on its being filled. Such lakes are chiefly found in hot rainless regions, and it often happens, in these districts, that when the supply is least, evaporation is at a maximum. This ever-changing difference between supply and evaporation causes these lakes to vary frequently in size and extent. Many of them are but craters of extinct volcanoes, and as such stretch over small areas. Lake Albano in Italy is of this class.

Functions of Lakes.—Lakes play an important part in the prevention of floods. In mountainous regions in which heavy rainfall or the melting of glaciers sends down to the valleys below a large supply of water, they act as regulators of the outward flow. An excellent instance of the value of lakes in this respect is afforded by a comparison of the St. Lawrence and Ohio Rivers. The St. Lawrence, being regulated by the Great Lakes, is not subject to serious floods; whereas on the Ohio, which has no lakes to flow through, floods occasionally rise to a height of 50 or 60 feet, and the river spreads to ten or twenty times its usual width. Lakes also equalise the temperature of a region. In summer their cool waters give rise to a temperate breeze, which blows as an on-shore wind and thus modifies the intense heat that might otherwise be felt. In winter the water, being warmer than the surrounding land, creates a more equable temperature. Thus the proximity of the Great Lakes gives the Lake Peninsula in the province of Ontario an almost maritime climate—a climate which is extremely favourable to cheese-making and also to the production of fruit. In the Hamilton Peninsula of Ontario splendid peaches and grapes are produced, and in the summer the ruby-throated humming-bird, whose habitat is semi-tropical, is constantly seen. The mean temperatures for Toronto, on Lake Ontario, are 24° F. (January) and 66½° F. (July); whereas at Montreal, about 2 degrees north-east of Toronto, the corresponding temperatures are 13½° F. and 71½° F. Lakes, as well as furnishing the most favourable conditions for the formation of deltas, act as filters and have no tides. Only on such huge bodies of water as the Great Lakes of North America is there a slightly perceptible movement of the water which may have the same origin as oceanic tides (see p. 256). Here also waves, which are only moderate in all other lakes, resemble those to be seen at sea.

Varying Features of Lakes.—Some lakes alter their positions as well as change their extent, varying with change of weather and season. Lakes of this kind are frequently to be met with in desert regions. Lake Lob Nor in Tibet has been known to alter its position in the shifting sands in which it is situated, so much so that at certain times its very existence has been disputed. The Great Australian Lakes—Eyre, Torrens, Gairdner, and Amadeus—do not shift their position, though they vary greatly in volume. At one time they have been found to extend over large areas; at others they have been known to shrink up until there is little left except a few stagnant pools of salt water. This change in volume is explained by the variation in supply and evaporation. Granted that the supply is great and the evaporation small, their area is large. If, on the contrary, the supply is small and the evaporation great, their area is small. Similar phenomena are also observable with regard to Lakes Tchad and N'gami in Africa.

Of those lakes which are situated at great altitudes, Lake Horpa Cho in Tibet with an altitude of 17,930 feet, Lake Askal Chin in Tibet with an altitude of over 16,600 feet, and Lake Titicaca with an altitude of 12,545 feet are the highest in the world. Lake Titicaca has its own drainage system, with many rivers flowing into it and one (the *Desaguadero* or "the emptier") flowing out. But despite the volume of water which is poured into it during the rainy season, the lake is growing steadily smaller under the joint influence of evaporation and the silt brought down by the rivers.

Salt Lakes.—A few lakes are remarkable for their great salinity and high density. Among these are Lake Van and Tuz Gol in Asiatic Turkey, the Dead

Sea * (1,290 feet below sea-level), Lake Urumiah in Persia, and Salt Lake in Utah. Nearly all saline lakes are to be found in warm districts. As evaporation gets rid of the water flowing into these lakes, their area and depth vary according to the weather or season. Between the wet and the dry season the shore-line (in most cases a flat one) may alter several hundred feet, and upon the expanse thus left dry there gathers a saline (and often fetid) incrustation. The scenery round salt lakes is extremely uninviting and settlements are seldom found on their shores. They are generally surrounded by arid plains. An explorer describes Lake Shirwa in South-east Africa as " a shallow sheet of foul salt water, lying in the flat central depression of extensive alluvial plains, its margin occupied by great malarial marshes." The dismal shores of this torrid quagmire are frequented by " crowds of flamingoes, cranes, and screaming water-birds, jostling one another for room and only adding to the depressing nature of the scene."

Depth of Lakes.—Although most lakes are comparatively shallow, yet there are a few that have been formed in very deep depressions. Lake Baikal in Siberia is the deepest in the world, a sounding of nearly 4,800 feet having been obtained, which, as the lake lies 1,360 feet above the sea, means 3,440 below sea-level. Lake Baikal is the largest body of fresh water in Asia, and is one of the few lakes containing fresh-water seals. In the British Isles, Loch Morar, situated in Inverness on the west coast of Scotland, and drained by a short river into the sea, is the deepest. Its elevation above sea-level is about 30 feet, and a sounding of 1,068 feet has been obtained in it. The Caspian Sea, with an area of 140,000 square miles, is the largest lake in the world. It is situated in an old sea-bed (confirmed by the fact that Caspian salts are very similar to ocean salts), and its level is 85 feet below the ocean-level. The land lying between it and the Black Sea is extremely low-lying to the north of the Caucasus, and it has been estimated that if the waters of the Black Sea were to be raised 14 feet above their present level a channel would link up the two seas. It is to be noted that the Caspian Sea lies in a region of small rainfall. Hence the influence of evaporation is the more marked. The Dead Sea, too, lies in a similar rainless region, and its bed, like that of the Caspian, is an instance of a sunk plain (see p. 422).

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* The Dead Sea (called also Bahr Lút or " Sea of Lot," " Sea of Salt," " Asphaltites Lake ") probably received its name from the fact that cities are fabled to lie engulfed in its depths. It is a little larger than Huntingdonshire. It lies in a basin formed by naked limestone cliffs; and its water is as clear and blue as that of the Mediterranean, " but salt, slimy, and fetid beyond description, tasting like a mixture of brine and rancid oil." " The human body will not sink in it, strive as the bather may." The step-like terraces round it are old beaches, which contain the shells of species still living in the Mediterranean. No fish live in the Dead Sea.

Distribution of Lakes.—Lakes seem to have a tendency to appear in groups. An examination of a map of each of the continents will show this peculiarity in their distribution. In the British Isles the Lake District in the north-west of England, where the lakes radiate from Dunmail Raise like the spokes of a wheel, affords a familiar example. In Europe we find most of the large lakes centred in the north-west of Russia. Here is the group which includes Lake Ladoga (the largest fresh-water lake in Europe), Onega, Peipus, Saima, and Ilmen, all within a comparatively small area. Outside this group are the small mountain lakes of the Alps and the Scandinavian system, and except for these there are very few lakes of any size on the continent. The same phenomenon of lakes occurring in groups is even more noticeable in the fine lake system that occurs in North America. There the central plateau divides each of the two distinct groups from the other. In one basin are Lakes Winnipeg, Winnipegosis, and the Great Bear and Great Slave Lakes; Lake Athabasca, Lake Wollaston, and Deer Lake of the Mackenzie basin; in the other basin are the lakes of the St. Lawrence—Lake Superior (32,000 square miles, the largest fresh-water lake in the world), Michigan, Huron, Erie, and Ontario. These lakes are important as a means of communication with the interior of the continent, and Chicago on Lake Michigan has all the appearance of a great ocean port, with its quays and shipping trade. Lake Winnipeg also has much shipping carried on upon its waters—a navigable waterway being provided by means of the Nelson and Saskatchewan Rivers almost to the foot of the Rockies. The Central African and Central Australian lakes also occur in groups; but a notable exception to the rule is seen in Lake Tchad in Nigeria. Other exceptions are Lake Titicaca in South America and Lakes Balkash and Baikal in Siberia. All mountain-ranges have, of course, their lake system, but the Himalayas are remarkable for the few lakes of any size they contain.

EXERCISES

1. What are *ribbon-lakes*? In what parts of the world are they common? What is their probable origin?

   [Long, narrow lakes, like Tanganyika and Nyassa, are from their surface shape so called.]
2. Explain why certain inland lakes are salt, while others are fresh. Give instances of both. (Camb. Jun. Loc.)

3. Write an account of some of the ways in which lakes have been formed and give examples. Discuss the economic advantages and disadvantages of lakes.
4. Explain why lakes are generally found in mountain groups, and not near mountain chains, and give some illustrations.
5. Draw a map of the rivers and lakes of the St. Lawrence basin. Name the rivers and lakes. Show the positions of and name the principal river- and lake-ports. Mark also the principal hindrances to navigation, and the means by which they have been overcome.
6. Describe the distribution of the lakes of the British Isles, and show how one of them was formed. (North. Univ. Matric.)

CHAPTER XXX

Coral Islands

The Formation of Coral.—In warm parts of the ocean there exists a minute marine animal called the *polyp.* These animals live in small colonies and each one builds for itself a small cell in which it dwells. The calcareous matter of which the cells are composed is derived from the sea-water, the polyp secreting the calcium so derived as it works away at its task of rock-building. As time progresses and the polyps die off, which they do on reaching sea-level, banks of the limy skeletons are formed. Having by slow accumulation reached the surface of the sea, these banks are exposed at low tide to the atmosphere and the heat of the sun. This exposure causes the mass to shrink and crack and break up into flakes and coral dust. Each returning tide helps to bump and grind this coral debris into a more and more solid mass, which, by reason of superincumbent pressure, becomes in the deeper parts of the banks hard rock, called **coral** rock. In those parts of the ocean where the polyps are very active, coral accumulates rapidly; but where the conditions are not favourable to the polyp, the rock is of very slow growth.* The polyp is found to be the most active in seas where the water is (*a*) of a fairly high temperature; (*b*) not very deep; and (*c*) clear and very salt.

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* The coral rock contains also such debris of marine life as fish bones, shells, and the hard parts of calcareous sea-weeds.

(*a*) The polyp does not exist, except in rare cases, in water that has a lower temperature than 68° F. For this reason coral formations are chiefly to be found in the tropics, and they are particularly prevalent in the Gulf of Mexico, off the south and west coasts of Florida, and in the western parts of the Pacific and Indian Oceans. Outside the tropical regions coral is only formed in those places where the influence of the warm currents flowing from the equator raises the temperature of the ocean to the required point. The Bermudas illustrate this : they are well outside the tropics, but the Gulf Stream provides a sufficient supply of warm water for the coral polyp. The Galapagos * Islands, on the other hand, though near the equator in the Eastern Pacific, are free from reefs, because of the stream of cold water brought up by the Peruvian current. There is also another remarkable feature in the distribution of coral due to the direction of ocean currents. A larger amount of coral formation may be observed around the islands situated off the east coast of each continent than about those lying off the west coast. This is because the direction of the ocean currents in the tropics is from east to west, the result of which is to make the western portions of the great oceans warmer than the eastern (see p. 310). Roughly speaking, coral formations are to be found on the windward side of all coasts within the tropics, provided the depth and nature of the water satisfy the remaining conditions.

(*b*) The coral polyp seems to flourish in shallow water and to be most active when the depth does not exceed from thirty to forty fathoms. At this depth the true reef-building polyp is commonly to be found at work. Of course the polyp can, and actually does, live and work at greater depths, in some cases as much as 100 fathoms. Such deep-water corals in warm latitudes may be covered by those living at intermediate depths, and these again by the true reef-builders. Hence a reef may be built up from a considerable depth.

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* Pronounce Gălâhpăgoss.

(*c*) The polyp does not thrive in dirty water. A map of the world will show the total absence of coral formation at or near the mouths of any of the great continental rivers within the tropics. The fresh and muddy character of the water in these places accounts for the non-activity of the polyp. Again, its greatest activity is seen where the sea is of great salinity and where the supply of food is to be obtained in large quantities. Hence in enclosed seas like the Red Sea myriads of these minute animals are constantly at work.

Coral Islands.—There are three distinct types of coral formation: (*a*) the fringing reef, (*b*) the barrier reef, (*c*) the atoll.

The **fringing reef** is a narrow bed of coral rock that is usually built on the platform round the shore of an island. As the reef grows, it inclines outwards and forms a fringe close to the shore. The seaward edge of the reef is generally higher than the inward, since the coral polyp is more active in those parts where food is more plentiful. Inside the reef there is not the same activity present, because the sand and mud brought down by the streams of the island help to kill the polyps. The size and extent of the fringing reef depends upon the degree of activity of the polyp and the age of the reef. In no case does the reef extend for any considerable distance from the shore, and its width scarcely ever exceeds more than a few feet at the most. When such a reef is built up to form a broad surface, a deposit of sediment, which is fatal to coral life, begins to collect upon it and to kill off the polyps.

Much of the sedimentation is due to the chemical action of the atmosphere, to weathering (see Chap. XXV), and to the agency of waves which break up the coral into fine particles on the top of the reef and thus form a deposit of fine coralline mud and sand. When the reef by growing outward has reached the edge of the platform on which it is built, it continues to grow on the heap of broken coral fragments which have fallen into the water. Without this bank of debris on the outer edge of the platform the water would be too deep for coral growth. The fringing reef then becomes a **barrier reef,** separated from the land by a more or less wide lagoon, but running in a line almost parallel to the coast. These lagoons are sometimes of sufficient depth to permit of their being navigated and they frequently provide excellent roadsteads for ships in stormy weather. The seaward edge of the barrier is steep and often descends abruptly into great depths. Barrier reefs are often of great length with varying breadth and are generally fringed with islets on the seaward side. The best example of this class of reef is the Great Barrier Reef, which lies off the east coast of Australia. It extends in a north to south line for a distance of over 1,250 miles from Torres Strait to Lady Elliot Island, and varies in breadth from 10 to 90 miles. The width of the lagoon between the reef and the coast varies from 10 miles at its narrowest point to 100 miles at its greatest. This barrier reef is built on the edge of the continental shelf, and this is proved from soundings taken off the eastern side of the reef, which go to show that the sea-bed there sinks abruptly to a great depth. Narrow openings pierce the reef in several places, many of which are navigable and allow vessels to enter the lagoon within.

The **atoll** is a circular reef of coral rock enclosing a shallow lagoon, whose bed is also formed of coral. Although the polyp is seen to be in a state of great activity on the surrounding reef, it is no longer at work on the bed of the lagoon. The explanation lies in the fact that as the reef increases in extent, it prevents a fresh supply of sea-water from entering the lagoon. In this way the polyp is deprived of its food-supply and dies off. The reef is generally very narrow, and scarcely ever reaches more than a few feet above the level of the surrounding sea. The Maldives, the Laccadives, and the Chagos in the western Indian Ocean, and the Paumotu, or Low, Archipelago in the Pacific, provide typical examples of atolls. In the Paumotus only four islands rise to more than 12 feet above sea-level. These islands are generally higher on the windward (east and south-east) side, where the wind and waves heap up coral sand into ridges. These ridges are often formed into a solid mass by water percolating into the sand, and the whole, cemented together by a glue of dissolved carbonate of lime, solidifies into firm rock.

Darwin's Theory as to Coral Islands.—Although the polyp flourishes in shallow water, there are many coral reefs where soundings have been taken on their seaward face of over 150 fathoms, from which depths masses of coral have been brought to the surface by dredging apparatus. Darwin accounted for the existence of coral at such depths by asserting that it was due to the subsidence of part of the ocean-bed at that particular spot. He therefore formulated the theory that first of all there formed round an island, close to the shore, a fringing reef; secondly, that, owing to the subsidence of the island, the fringing reef became a barrier reef with a lagoon between the reef and the shore; and last of all, the subsidence still continuing, that the island sank out of sight alto-

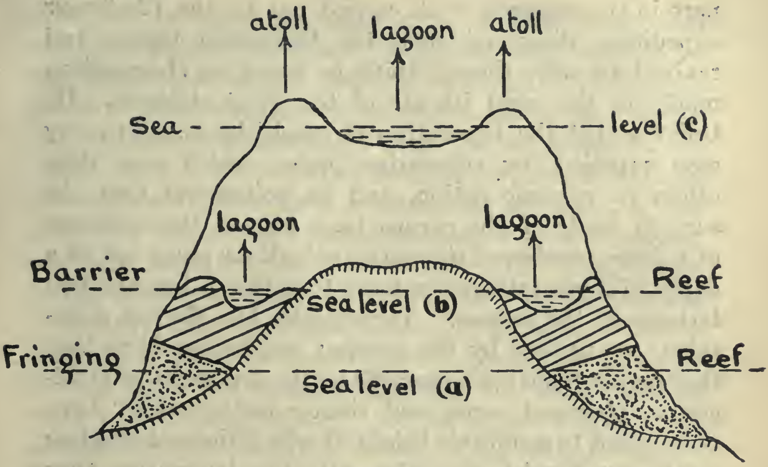

FIG. 114.

gether, leaving an atoll—a mere ring of coral encircling (with or without a break) an inner lagoon. The Darwinian theory may be more clearly understood if we imagine that the diagram (fig. 114) represents an island surrounded by a fringing reef, the sea-level then being shown by the broken line (*a*). As the island slowly subsided into the ocean the growth of coral would keep pace with the subsidence, with the result that a barrier reef would be formed separated by a lagoon from the shores of the island. At the same time subsidence would have brought the sea-level to the position represented by the broken line (*b*). Finally, if the subsidence and the growth of coral continued, the island would eventually disappear beneath the surface and an atoll would result—nothing more then being seen above sea-level than (*c*) a somewhat circular ridge of coral enclosing a central lagoon.

Murray's Theory.—Dr. Murray, who took a very active part in the research work carried out by the *Challenger* expedition, disagreed with the Darwinian theory and revived an older theory which he based on observations made on the coral islands of the West Atlantic. He believes that the foundation of coral islands is in every case supplied by submarine peaks, which owe their origin to volcanic action, and he points out that the surveys made of the oceans have proved the existence of a large number of submarine elevations rising out of a depth of 2,000 fathoms or more to within a few hundred fathoms of the surface. These peaks, Dr. Murray maintains, are utilised by the polyps; but he considers that they do not build upon them till by the deposition of globigerina, pteropod oozes, and similar matters, they have been raised to a suitable height at which the reef-building corals can flourish (fig. 115). On the foundation thus

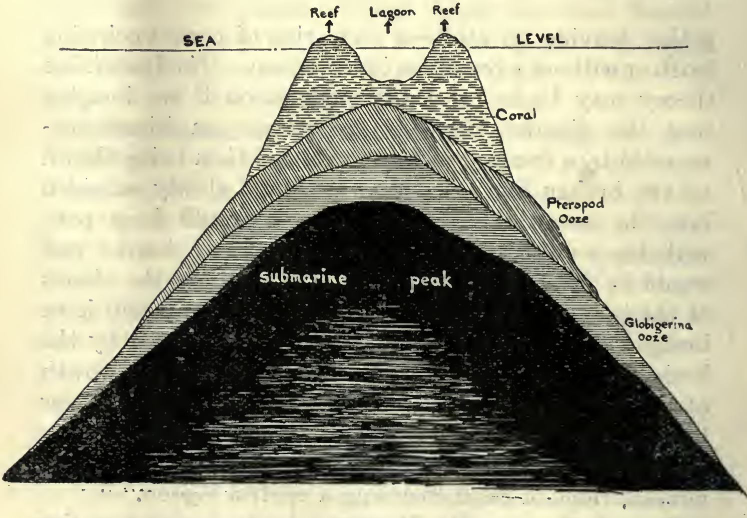

FIG. 115.

provided, or upon the edge of a shallow continental shelf, the polyps build, and they build more rapidly on the outside than on the inside, because the outside polyps get more abundant food than those on the inside. Hence the outside rim is always growing, but the corals on the inside rim, cut off from their food supply, die on reaching the surface. Thus, upon a submarine elevation, a ring or atoll is formed ; or upon a continental shelf a fringing, and later, a barrier reef is built up. The main points in Dr. Murray's theory to observe are : (*a*) he does not necessarily believe in subsidence, (*b*) he affirms that a platform is built for the polyp to begin on, (*c*) he shows that it is on the seaward side that the most vigorous coral growth takes place. Of these three points the second is the characteristic feature of the Murray theory. The Darwinian theory emphasises the development of the atoll from the fringing reef through the barrier reef by the subsidence of the foundation ; the Murray theory emphasises the direct building of the atoll upon a steadfast foundation which has first been levelled up by ooze deposits to the zone in which the coral-builders can thrive. The Darwinian theory also explains the development from fringing reef to barrier reef by subsidence of the foundation ; the Murray theory explains the same development by the simple outward growth of the coral upon a bank of its own debris, forced off from the edge of the fringing reef by the action of breakers.

Man on Coral Islands.—Many coral islands—and even atolls—in time become fertile and populated. Their fertility is due to the weathering of the rock and to the action of the sea, which breaks up the coral rock into small fragments and particles. Coral dust is thus formed, and in due time seeds carried by birds are dropped and germinate on the islands. Palm trees and like forms of tropical vegetation then appear. Additional soil is supplied by floating pumice, the product of some volcanic eruptions, which the natives in some islands gather and pound into dust as a fertiliser for their crops. Stone of a denser texture than coral rock for the purpose of implement-making is a great want, but this too is supplied by floating logs which carry stones among their roots. Streams on atolls are of course non-existent, but rain-water lodges in the hollows of the reef and is even found below the surface. Besides man, birds inhabit all the islands, but no coral island ever possessed any mammals till the white man brought rats and mice in his ships and introduced the pig. The inhabitants of such islands are naturally good swimmers and boatmen.

EXERCISES

1. The limestones of South Devon contain great quantities of coral-skeletons. No polyps are found living there now. What sort of climate must have existed there when these limestones were first formed?
2. Where are reef-building coral polyps found, and under what conditions do they flourish?
3. Describe the structure of a coral island and discuss the mode of formation of such islands. (Oxf. Jun. Loc.)
4. Describe carefully the different forms of coral reefs and islands. Explain how they are grouped in the Pacific Ocean. (Camb. Sen. Loc.)
5. Explain with diagrams the meanings of the terms: atoll, barrier reef, fringing reef.

   Describe a theory to explain how an atoll is formed. (Oxf. Jun. Loc.)
6. Write a brief description of the three recognised types of coral reef and their origin. (Camb. Jun. Loc.)

CHAPTER XXXI

Glaciers

Snow-line.—There are two snow-lines—an upper and a lower. Above the upper, snow practically never melts; between the two, snow melts in summer except in sheltered places; below the lower, snow melts whenever the sun shines. The upper snow-line is known as the limit of perpetual snow. Above the upper snow-line the air never has a higher temperature than 32° F., no matter how great the amount of sun-heat that passes through; this is why so very little snow falling above that line can melt. Over the greatest part of the regions near the poles this limit of perpetual snow is sea-level. It is about 5,000 feet above sea-level in Norway, about 9,000 feet in Switzerland, and 18,000 to 20,000 feet at the equator. Our British hills are not high enough to have perpetual snows; that is, they are below the upper snow-line, although quite high enough to be above the lower. Depressions on the higher slopes of mountains and tablelands above the upper snow-line act as gathering-places for snow. These permanent sheets of snow, persisting from winter to winter, are called snow-fields, and if Nature made no provision for the removal of excess, the snow would increase from year to year indefinitely. As it is, the snow on some snow-fields is several hundred feet thick. Such snow-fields rid themselves of the surplus snow in three ways: (1) evaporation, (2) avalanches, (3) glaciers. Even in frosty weather snow often disappears slowly by evaporation; for just as water-vapour can change directly to snow, so snow can pass directly to water-vapour without first melting. Snow-fields lying on the steeper slopes of mountain-sides, or the edges of snow-fields overhanging a steep slope, are always tending to slip or fall down with a crash into the valleys below. This sudden rush of masses of more or less consolidated snow is called an **avalanche.*** In Alpine countries a large amount of the annual snowfall is removed in this way. Hence any pine forests that lie on the slope behind the upland villages and fields are carefully preserved, that they may ward off certain ruin and devastation; and on the Canadian Pacific Railway "snow-sheds" are built for miles along parts of the line as it passes through the Rockies, in order that the snow may slide over them without blocking the line.

Formation of Glaciers.—The chief means of removal of surplus snow from above the snow-line is the **glacier.** The snow that lies in the depressions between summits of the high mountains becomes compacted for the same reason that fleecy snow-flakes when squeezed together in the hand form a hard snowball, the air between the particles of snow being, so to speak, squeezed out. The pressure on the underlying snow increases with each successive fall of snow, and eventually the lower layers are turned into ice. This compacted snow is called by the French name *névé* or by the German name *firn.* Under pressure from the upper layers, the lower parts of the *névé* begin to move slowly down the valleys leading from the snow-fields. It is chiefly during this movement that the air is pressed out, and the *névé* becomes solid transparent ice, a moving tongue or river of ice creeping gradually down the valley by the action of gravity. Such a river of ice is called a glacier.

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* From the Old French *à val,* to the valley, downward.

The Motive Power of the Glacier.—A glacier, although it consists of solid ice, moves along down its valley past and over obstructions, and accommodates itself to the windings and irregularities of its channel. Many explanations have been offered of this power to move, but the true theory is probably not single but collective. The following are considered to be the chief elements in glacier motion. If two pieces of ice are pressed together the surfaces in contact melt, the water thus formed freezes again round the junction, and so cements the two pieces of ice into one. The pressure lowered the melting-point of the ice, and in so doing helped it to melt. But as soon as the water from the melting reached the outside of the junction there was no pressure on it, and it was again able to freeze at 32° F. The water was, however, at or even below that temperature, hence it froze and joined the parts together. This process is known as *regelation.* So then, as the glacier lies with its weight upon the valley slope, pressure and tension due to inequalities in the channel cause the ice to be continually broken into fragments. These breakages allow the ice to accommodate itself to the irregularities of the channel. Pressure from behind, however, squeezes the fragments together, regelation takes place, the fractures are healed, and the glacier by being successively fractured and frozen is enabled to surmount obstacles which it cannot push out of its way. It has also been suggested * that the movement of glaciers may be explained in another way, still connected with the regelation theory. When the glacier comes to an obstruction the pressure of the ice from behind against the obstruction lowers the melting-point of the ice at that place (see p. 483). (That is, the ice is able to melt at a temperature where without the pressure it would remain frozen.) The *water* from the melted ice *flows past the obstacle and freezes again.* And so the glacier moves slowly on by the continuous pressure from behind. Another theory * is that ice, though it appears to be a brittle solid, is really plastic like warm sealing wax, and can flow over obstacles. Again, the water that sinks down into the cracks of the glacier from the surface freezes, expands, and subjects the ice below to great stress. This stress, tending to split the ice vertically, has the effect of moving the ice, and since gravity helps, the movement must be down the valley. These theories, together with the sliding due to gravity where the bed of the channel allows it, are probably all involved in the correct explanation of a glacier's movement.

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* By Professor James Thomson.

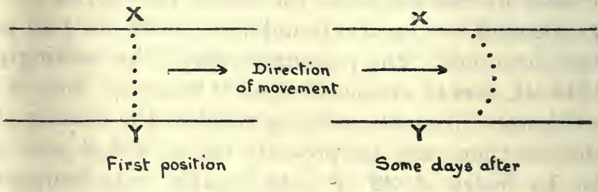

FIG. 116.

Rate of Movement.—That a glacier really moves may be easily demonstrated by fixing a row of stakes straight across it, marking the banks at X and Y (fig. 116) to show where the row started. In a few days the row will have become curved, and *all* the stakes will be found lower down with respect to the starting marks on the bank. This new arrangement of the stakes shows that the middle of the glacier moves faster than the sides. But the stakes were originally placed upright in the ice; at the second examination they are found oblique with the top of the stakes inclined forward. This shows that the movement, like that of rivers, is faster at the top than at the bottom. The rate of movement of glaciers varies. Among the Alpine glaciers the rate averages between 100 and 500 feet a year, or, roughly speaking, about as quickly as the hour hand of a watch moves. The Mer de Glace of Chamounix moves on the average an inch an hour along the middle line. The summer movement is always greater and the winter movement always less than this average. The summer rate of movement of the Upernavik Glacier in Greenland is a yard an hour. Dr. Herbertson reckons that the speed of a glacier is roughly a thousand times less than that of a river of the same size over the same slope.

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* This theory was put forward by Principal Forbes of St. Andrews.

The End of the Glacier.—Starting from these reservoirs of *névé* above the upper snow-line, glaciers move down until a point is reached where the ice is being continually melted, *i.e.* where the loss due to melting is exactly balanced by the supply from above. The end of the glacier is called the *snout.* When the melting takes place rapidly the snout is tapering; when the melting is slow the end is cliff-like and is called a *Chinese wall.* In the Alps, glaciers descend from points of varying height above 10,000 feet to points varying from 4,000 to 5,000 feet high.*

Glaciers and Rivers Compared.—Glaciers are like rivers in the following respects:

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* A glacier may even descend far below the tree-line to the level of the cultivated fields.

(*a*) They receive tributaries; (*b*) they flow over breaks in the bed, forming ice-falls instead of waterfalls; (*c*) they flow round corners; (*d*) they flow faster in the middle than at the sides; (*e*) they flow faster at the surface than at the bottom; (*f*) they wear away their banks and bed; (*g*) they transport matter from a higher to a lower level; (*h*) they deposit their load at the lowest level; (*i*) they drain off superfluous water (in the form of snow).

They are unlike rivers in the following respects:

(*a*) They can move up an incline; (*b*) they have no towns on their banks; (*c*) they carry most of their load resting on the surface; (*d*) they are sometimes at their lower end so covered with deposits of soil that grass grows on them. Thus on the lower ends of certain Himalayan glaciers goats and sheep graze, and some Alaskan glaciers actually carry large forests ("on ice").

Crevasses and Séracs.—Bending from side to side round corners, and travelling over a rocky, uneven floor, the glacier becomes split by fissures called *crevasses*. These rents sometimes open wide, forming abrupt chasms reaching to the bottom of the glacier. Where an icefall is very steep or irregular the ice cannot descend in one unbroken sheet, but becomes cracked and splintered into segments and pinnacles called *séracs*.

Transporting and Erosive Power of Glaciers.—Glaciers carry their load both on the ice and in the ice. Fragments, loosened by the frost from the cliffs and mountain-slopes as the ice moves past the steep valley walls, fall and find a resting-place on the glacier. This material lies along the sides of the glacier in long, continuous heaps called lateral **moraines.** Where two glaciers meet, the two inner moraines unite and move along the medial line of the combined glacier. Thus lateral moraines become medial moraines (fig. 117). Many portions of rock, large and small, fall into crevasses and are either carried along in the mass of the ice or fall to the bottom, where, sharing the motion of the glacier, they are dragged along scratching and rasping the rocks of the bed, and being in turn scratched and rasped by them. Such rocks are said to be "striated." The rocky material carried thus in the sole of the glacier is called the ground moraine. The scratchings on the rock surface at the bottom and sides of a glacier will be parallel and will

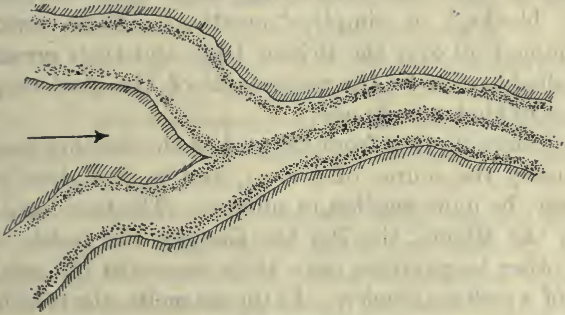

FIG. 117.

have a general direction down the valley. From this it is possible to recognise where glaciers have formerly existed and to trace the direction in which they have moved. In northern Europe and in northern America the distribution of these striated and smoothed rocks is sufficient proof that formerly these two parts of the earth were under sheets of moving land-ice, just as Greenland is to-day. In Great Britain during the geological period known as the "Ice Age" or the "Glacial Period," the ice-cap extended as far south as the valley of the Thames. But during part of that period these islands were submerged under the waters of a sea on which floated icebergs on their way southwards. As these icebergs came southward they dropped their ground-moraine upon the bed of this icy sea. Then this sea-bed was uplifted, bringing with it the gravel, clay, and rock-boulders; and the beds of clay containing the scratched boulders (boulder-clay) are to be found all over the country as far south as Finchley, near London. Occasionally the boulders are very large, and as, coming from indefinite distances from where they are at present found, they have no geological connection with the underlying rock, they are called erratic blocks,* or simply "erratics." These erratics are common all over the British Isles, and their presence is a valuable clue to the movements of the glaciers and icebergs of that remote age.

The waters flowing from the end of the melting glacier are usually the source of a river, and such a river will, of course, be more swollen in summer. The Garonne, the Rhine, the Rhone, the Po, the Ganges, the Indus, and many other large rivers have their source in the muddy water of a melting glacier. As the ice melts, the boulders, fragments, gravel, sand, and silt are deposited in irregular heaps, together forming the terminal moraine. This debris of the terminal moraine is sorted out by the running water, the finer material being carried farther down the valley. Glaciers bring down from the mountain-tops the potential water of the snow-fields. Some of this becomes water during the course of the glacier towards the snout. Water from surface melting flows in irregular channels on the surface of the glacier, finally plunging down a crevasse with a swirling movement. If any erosive material be in this water, a circular shaft is worn down to the bottom of the glacier and even into the bed. The shafts are called *moulins*, the holes so worn in the bed are called "pot-holes" * or "giant's kettles." A group of pot-holes, some of them of great size, is one of the curiosities of Lucerne † in Switzerland; they have been left behind by a glacier which once covered the site of the town. The water that falls to the bottom of the glacier flows along underneath, and emerges as a stream of milky-looking water from the ice-cave that is usually found at the snout. The milky appearance of the water is due to the suspension in it of the particles formed by the grinding action of the glacier against the surface of its bed. Therefore, somewhere up the valley there must be great erosive waste going on to account for this plentiful supply of mud.

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* For a long time in Scotland these erratic blocks were attributed to the agency of wizards, brownies, fairies, and even to the Evil One himself. *Putting the stone* was supposed to have been one of the favourite occupations of these personalities.

Glacier Evaporation.—Under the sun's rays all glaciers suffer loss by evaporation from the surface. This lowering of the surface is called *ablation* of the surface. Ablation is made manifest in the following way: Many large flat pieces of rock fall upon the surface of the glacier. The ice below the slab is protected from loss by evaporation, but the surrounding parts of the glacier, not so protected, are insensibly wasted away. Thus the stone seems to rise, as it were, out of the glacier, though really it is the ice around the rock that is melting. After a time the ice-pedestal becomes too slim to support the rock, or *perched block* as it is called, and it is dropped upon the ice, to be raised up again as formerly. Curiously enough, little isolated stones have exactly the opposite effect. They become heated by the rays of the summer sun, melt the ice around and under them, and so sink into the glacier instead of rising above the surface on an ice-table. When loss due to evaporation and melting at the snout is greater than the supply, the snout of the glacier retreats up the valley. As a glacier thus retreats a heap of stones and rubbish is left (terminal moraine) which dams up the valley, causing the water from the melting ice to form a lake. Lake Geneva is an example of this. When by a general increase of temperature a glacier as a whole melts, the ground which it once occupied may sometimes be seen to have assumed the form of smooth undulating prominences, in appearance not unlike sheep lying at rest on the ground. These rounded mounds are called *roches moutonnées*.

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* Exactly the same phenomenon can be observed in rocks by the side of a stream. If a loose stone lodges on the rock, it may be worked round and round by the action of the stream and may in time scoop out a pot-hole.

† In the Gletschergarten or glacier-garden one of the pot-holes is 30 feet deep and 26 feet wide.

Glacier Lakes.—The valley of the glacier must of necessity become gradually and sensibly deeper by the continual removal of material. And this deepening is not uniform over the whole of the valley. There are places where either the glacier exerts a grinding force greater than usual, or where the bed over which it flows is softer than usual. Hence some parts are more deeply scooped out than others. After the disappearance of the glacier, these rock-basins become filled with water. Some scientists believe that the rock-basins existed before the glacier movement and were filled with decomposed rock material which was scooped out by the moving glacier. The rock-basins, however formed, are now lakes, and are regarded as characteristic of a glacier district.

Distribution of Glaciers.—Glaciers are of two kinds—

those that move down valleys from the snow-covered mountain-tops and melt at some definite point below the snow-line, and those that cover lands of continental extent with a great ice-sheet. The former are called **valley glaciers,** the latter **continental.** The valley glaciers of Europe are well developed in the Alps where occurs the longest glacier in Europe (Aletsch), in the Caucasus where occurs the second longest, and in Scandinavia where from the central plateau of the north many large glaciers descend the valleys. In the Pyrenees are some small hanging glaciers which lie on the steep slopes of the sides of the valleys. The valley glaciers of Alaska are among the finest in the world, of which the White Glacier, the Muir, and the Malaspina are the best known, the last named bearing a very luxuriant growth of pine forest (see p. 470). The Malaspina belongs to what is known as the piedmont * type, because after flowing to the base of the mountains it pushes its way over the level plain for a considerable distance towards the sea. The glaciers of the Rockies south of the Canadian boundary are somewhat small, one of the largest being the Whitney of Mount Shasta in Nevada. In the Andes of South America glaciers are few and small, except in Patagonia and Tierra del Fuego, where the mountains receive the west winds from the Pacific, in consequence of which the more prominent peaks bear great ice-sheets which in some cases glide down to sea-level. In Africa small and insignificant glaciers are known near the summits of Mounts Kilima-Njaro and Kenia. The longest and biggest glaciers in the world are in the Himalayas, where many are over thirty miles in length and some are said to be nearly 100 miles long. In the New Zealand Alps are the most beautiful glaciers in the world. The lower ends of these enter a region of subtropical forests where the tree-ferns grow. The Franz Josef in the southern Alps, at about the same latitude south as Florence is north, is only 8½ miles long (the Tasman in the same range is 18 miles long), but it is considered by some to be the most beautiful glacier in the world, by reason both of its wonderful ice-forms and of its picturesque setting. The Fox is another small but beautiful glacier in the same mountains.

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* French *pied,* foot, *mont,* mountain. The Piedmont district of North Italy is hence so called.

The **continental glaciers** are to be found in the Arctic and the Antarctic regions, where the long winters allow vast fields of snow and ice to accumulate. It was the soft snow in the lower reaches of the famous Beardmore Glacier in Antarctica that, by reducing the pace of the return party, proved so disastrous to the Scott Expedition of 1910–13. In fact, most of the lands in Arctic regions, like Spitzbergen and Greenland, are covered with immense sheets of ice thousands of feet thick. In Greenland the movement of the ice is from the centre towards the sea in all directions, so that there seems to be an accumulation of ice upon high ground somewhere in the interior in the form of an ice-plateau. Near the coast of the island mountain-peaks project through the ice-cap, and these the Eskimo call *nunataks*. The sheet of ice covering the continent of Antarctica is believed to be miles in thickness.

Evidences of Glacial Action.—Glaciers leave behind them a fairly permanent record of their existence and work. The chief evidences of their presence are the following. Glaciated hills are rounded, not irregular in outline; glaciated valleys are flat-bottomed or U-shaped, not V-shaped like the typical river-valley. A main valley recently deepened by a glacier is as a rule at a lower level than its tributary valleys (which are therefore called "hanging valleys"). The upper end of a glaciated valley has frequently a flat circus-like area, called a *cirque*, *corrie*, *cwm*, or *combe*, in which a lake often occurs. Glacial deposits are easily recognised by the striated stones. The rocks which formed the bed of the glacier have striations more or less parallel which show the direction of the glacier's flow. Lastly, perched blocks are often found on what was originally the side of the glacier. They are quite dissimilar in nature from the rocks on which they rest.

Icebergs.—Continental glaciers have no terminal moraine. The end of the glacier is continually pushed forward into the sea, and as ice is lighter than water, the upthrust of the water forces the protruding sheet or tongue of ice to break off upwards into huge fragments which then drift away as icebergs. These floating ice-mountains or ice-islands are carried by currents for hundreds of miles towards regions of warmer water and atmosphere, melting rapidly as they go, and littering the ocean-floor with the debris * which escapes from its ice-bondage. On one iceberg there may be a load of rock and earth as great in weight as 50,000 tons. Bergs from the north come as far south in the Atlantic as the Azores, and those from the south come as far north as the Cape of Good Hope. Therefore the area over which icebergs carry on their work of deposition is very large. Bergs occasionally become stranded on island coasts and, remaining for years, materially affect the climate. Most of an iceberg is under the water; for every foot above water there are nearly 9 feet below. So that if a berg were 200 feet above the surface of the sea, it would have nearly 1,800 feet of its total height below the surface. Icebergs have been seen more than a mile long and 500 feet high above the sea. It was after entering a field of ice with miles of bergs and floes that, on April 15, 1912, the *Titanic* struck her side a glancing blow on a mass of ice below the water in latitude 41° N., longitude 50° W.*

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* The debris from an iceberg is called a trailing moraine or a precipitated moraine.

Ice-floes.—Besides the iceberg there is another kind of floating ice-mass. In the polar seas in winter the surface becomes frozen over. First thin flakes of ice are formed; this is known as sludge. When this has thickened a little it is called pancake ice; and finally it forms itself into complete covering called the ice-field, which is, however, not a smooth sheet of ice like that found on an English lake or river, but is covered with hummocks of ice and snow. In summer the ice-field breaks up into flattish fragments called ice-floes. A number of these jumbled together forms pack-ice, and when two fields of pack-ice drift together, any ordinary ship that may be caught between would be crushed by the grinding of the ice. It was to meet this danger that Nansen's famous vessel, the *Fram*, was specially constructed, so that it might be able to resist the grinding and crushing action of the ice. It was owing to the roughness of this same pack-ice that Nansen had, in 1895, to turn back from his "dash to the Pole" in latitude 86° 13′ N. An ice-floe is really a kind of iceberg, but greater in superficial extent, though generally less in mass. There is besides a very important distinction between the floe and the berg. The berg, being born on land, carries out to sea masses of rock and beds of detritus; the floe, being born at sea, carries no such material. There is another form of iceberg, small compared with either the true berg or floe, which is in origin almost like a floe, but which does the work of a berg. Along the shores of Greenland, for instance, the freezing sea-water forms a sort of shelf called the "ice-foot" upon which falls debris from the overhanging cliffs. The ice-foot breaks up in summer and floats away in fragments, carrying the rock-debris with it.

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* In less than three hours after striking the ice, the *Titanic*, the finest ocean-liner of the time, sank, with a loss of 1,513 souls out of 2,224 on board.

The Glacial Period.—It is generally supposed that during the periods when the great polar ice-caps covered so much of the northern hemisphere the tilt of the earth's axis was much greater than it is now, and that the orbit of the earth round the sun was more eccentric than it is now. That is to say, when the earth was in aphelion its distance from the sun was greater, and when in perihelion its distance was less than now. With the earth in an extreme aphelion, and its northern pole at an excessive tilt away from the sun, the northern winter would be so long and severe that the accumulations of ice and snow would not disappear during the succeeding short summer. And so in time the northern hemisphere became subject to severe glacial conditions, while the southern hemisphere enjoyed the very opposite climatic conditions.* This may perhaps have lasted ten or eleven thousand years, during which time a reverse of axis-tilt took place, reversing the conditions in each hemisphere. The small axis-tilt of the present day together with an orbit of small eccentricity has changed the differentiated polar climates to conditions of similar and almost equal glaciation. Geologists trace at least four of these glacial periods in the northern hemisphere, with interglacial periods between. The lowest and therefore oldest boulder-clay (see p. 472) covers vast areas in the British Isles and northern Europe, and, as the first ice-sheet was by far the greatest of all, it is found farther south than the younger beds. The rock-surfaces on which the boulder-clay rests are either smoothed and striated or very much crushed and broken. Between this oldest boulder-clay and the youngest beds are the interglacial beds containing such fossils that prove the existence of intervening genial climates. In Europe these morainic deposits, called post-tertiary, are found in Central France, in the Pyrenees, the Spanish Sierras, in Corsica, the Apennines, the Vosges, the Carpathians, and all over Germany and most of Russia. In North America they are found on a very large scale, and in many other parts of the world such as New Zealand, Tierra del Fuego, are to be found evidences of former excessive glacial conditions. The most pronounced features of the results of these glacial periods are threefold—the formation of soils, the formation of lakes, and the formation of waterfalls. The soil of the New England States and of the prairies of America is largely boulder-clay.* In many cases the boulder-clay soil remains after the total or partial disappearance of glacial lakes, as is the case in the wheat-lands of southern Canada. The whole of the great wheat-belt of the Red River Valley was formerly one huge lake, of which Winnipeg and Winnepegosis are the last remnants. Before the final disappearance of the last ice-cap the drainage from this huge lake took a southward direction to the Gulf of Mexico. The lakes of Finland cover a region which is a labyrinth of lakes, marshes, and hills. These lakes have been caused by the alteration of the natural river-drainage due to deposits left by the great ice-sheet. In England, the Vale of Pickering (Yorkshire) was once filled with lakes formed by the advance of the ice-sheet across the general slope and the consequent damming up of the natural drainage. In Scotland the many lakes that lie in the broader valleys are the result either of glacier erosion or of the damming up of the valley necks by terminal moraines. The Outer Hebrides are full of small lakes lying in glacier-eroded hollows, here and there being found those formed by a combination of eroded rock-basin and morainic barrier. In Inverness are the famous "parallel roads" of Glenroy, consisting of a series of alluvial terraces running along the sides of a valley at the three different levels of 856, 1,065, and 1,149 feet respectively. They mark the margins of a lake created by a morainic barrier. Formerly, glaciers passing by the mouth of the valley prevented the outflow of the accumulated waters, and the three different levels show the beaches or wave-cut shore-lines of the lake during three different glacial epochs. But while glacial action has in many cases laid down soil, there is evidence of cases where it has scraped away every particle of soil from a whole district, *e.g.* some of the highlands of eastern Canada, where large areas are covered with nothing but bare rock, or at most a very thin, stony soil. Glacial action is also supposed to have scraped from the surface of Ireland all the later or upper coal-seams, leaving only the earlier or deeper formations. The upper seams consisted of the soft or bituminous coal; the deeper seams that are now mined in Queen's Co., Kilkenny, Tipperary, Carlow, and Co. Tyrone are of the harder anthracite.

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* This theory is borne out by the discovery of deposits of coal in Antarctica, and by the evidence of glacial action in the north temperate zone.

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* Sometimes also called *till*.

EXERCISES

1. How far have ice-action, wind-action, or river-action been instrumental in characterising Swiss scenery?
2. Why do icebergs float? What proportion of an iceberg is immersed when floating in sea-water? What

is the height of an iceberg of which a mass 70 feet high is seen above the sea-level ?

3. What are the chief points of resemblance and of difference between valley and continental glaciers ?
4. Name some facts which show that glaciers once travelled over districts where they are not now found.
5. Where are glaciers found ? In what ways do they transport material ? What are the characteristics of that material ? (Camb. Jun. Loc.)
6. Write a short description of a glacier.

   Explain (*a*) how it is formed, (*b*) how and why it moves, (*c*) what part it plays as a denuding agent. (Oxf. Jun. Loc.)
7. Give an account of a glacier, describing its formation and physical features. What are the characters of a district over which a glacier has formerly moved ? (Oxf. and Camb. Lower Cert.)
8. What evidences are there of the existence of ancient glaciers in Great Britain ? (Oxf. Jun. Loc.)
9. Give an account of the glaciated districts of Europe, explaining the influence the glaciers have on the rivers draining them, and illustrating the dependence of the height of the snow-line upon aspect and precipitation. (Oxf. and Camb. Higher Cert.)
10. Describe as fully as you can the conditions which favour the formation of glaciers.

    How do glaciers give rise to icebergs ?

    Can you account for the distribution of icebergs usually found in the North Atlantic ? (Oxf. Sen. Loc.)
11. Describe an experiment to show that the melting-point of ice is lowered by increased pressure.

Define *regelation*, and give two examples of it with explanations. (Oxf. Sen. Loc.)*

12. Describe an Alpine glacier. Compare it with the Greenland ice-sheet. What evidence is there to show that glacial conditions formerly prevailed in Britain ? (Lond. Univ. Matric.)
13. Give a short description of each of the following : (*a*) *névé*, (*b*) *roches moutonnées*, (*c*) medial moraine, (*d*) crevasse.
14. Give some account of the chief effects of ice on the earth's surface. (Oxf. Jun. Loc.)

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* It should be noted that increased pressure *lowers* the melting-point of those solids that do *not* expand on melting; but that it *raises* the melting-point of those solids that *do* expand on melting (see pp. 371 and 468).

CHAPTER XXXII

Distribution of Plants and Animals

Introduction.—" The earth is the dwelling-place of a vast and varied series of living things which move through the air and people both land and water." The living things on the earth may be divided into two great 'kingdoms'—the animal and the vegetable. The various animals (and this includes the fishes) living in and common to any particular region are called the **fauna** of that region, and to the various trees, shrubs, herbs, and other forms of vegetable life the name **flora** * is given. The subject of the distribution of the flora and fauna of the world is a most complex one, and it is especially so in the case of the two vagrant families—the birds and the fishes. The majority of birds, since they have the power of flight, cannot very easily be apportioned to this or that part of the world, and later on it will be shown that hard-and-fast rules cannot be definitely laid down concerning their distribution. In the same sense there can be fixed no limited distribution areas for a great many of the fishes.

The great determining factor governing the distribution of flora and fauna in any region is temperature ; but it is only one of many. If it were the only one, then lines of latitude, or at least isotherms, might be taken as boundaries of zoological and botanical zones. It is true that botanical zones have been mapped out; but though classification of distribution in this way succeeds better with flora than with fauna, it is far from ideal. Nor can the distribution be mapped by continents; for what is true of northern Siberia is not true of southern India, and North Africa happens to agree with southern Europe. One of the best methods of dealing with the distribution of plants and animals is to follow the natural plan first suggested in 1857 by Dr. P. L. Sclater, and afterwards adopted with modifications both by Dr. A. Russel Wallace in his *Geographical Distribution of Animals*, and by Professor Alfred Newton of Cambridge. Dr. Marion Newbigin, in her book *Animal Geography*, has suggested a plan whereby the climatic regions of the earth are taken as the distinctive homes of certain characteristic fauna; but this plan is open to many objections.

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* *Flora* may of course be marine as well as terrestrial.

The Seven Regions.—The world as divided zoologically by Dr. Wallace and Professor Newton consisted of but six regions; but it is considered advisable here to combine the two plans, and increase the number to seven. These seven regions are, strictly speaking, only zoological; taken as botanical regions, they are too big and require a good deal of subdivision. The regions will, however, be dealt with as both zoological and botanical. The zone-map of the world's flora will be specially mentioned afterwards. The seven regions are:

1. **The Palæarctic,** including Europe, temperate and northern Asia, and Mediterranean Africa.

2. **The Nearctic,** including the New World (with Greenland) as far south as the middle of Mexico.

3. **The Neotropical,** including the New World from the middle of Mexico southwards, and the West Indies.

4. **The Ethiopian,** including all Africa south of the

Atlas Mountains, South Arabia, and Madagascar with the Mascarene Islands.

5. **The Oriental,** including India south of the Himalayas, southern China, Borneo, Sumatra, Java, and the Philippine Islands. This region is separated from the next by a narrow strait (about 20 miles wide) which lies between the islands of Bali (Oriental) and Lombok (Australian). The boundary that passes through this strait is known zoologically as **Wallace's line,** and is named after Dr. A. R. Wallace, who first called attention to the existence of this important boundary.

6. **The Australian,** including Celebes, New Guinea, Australia, and the Pacific Islands.

7. **The New Zealand,** including the two large islands of that name, and extending from Norfolk Island in the north to Emerald Island in the south.

General Conditions of Distribution.—The chief cause affecting the distribution of plants is undoubtedly climate. As a general rule, transportation being granted, similar climates produce similar species. This follows since three of the four great factors for proper plant growth are *light, heat,* and *moisture,* and these depend upon the annual proportions of day and night, of summer and winter, of rainfall and drought—or, in a word, climate. The other factor for proper plant growth—a sufficient supply of suitable and soluble plant food—is not so vital as climate, since plants are capable of much adaptability to environment. All the factors being present and operative, there is no limit except that of space to the abundance of plant life. The distribution of animals also depends upon climate, but not to such a great extent as in the case of plants. A cold and wet climate is not favourable to animal life, but a hot and dry one, or a hot and moist one, is. Thus the bulk of South America, being a continent of moist heat, is the home of insects and reptiles that like such conditions; and Africa, a continent on the whole of dry heat, has a quite different, though equally prolific, faunal life, being the home of the largest mammals.

Animal Distribution and Land-features.—The physical features of any region greatly affect the distribution of animals within that region. Some animals, like the goat and the chamois, are by their nature confined to mountainous regions; some can exist only near water, such as the otter, the beaver, and the hippopotamus; some only in open country, like the giraffe, the camel, and the zebra *; while some, such as the lion, the tiger, and the elephant, can live equally well in open country or in forest.

Oceans, seas narrow but deep, deserts, and mountain-ranges are in most cases effectual barriers between one region and another, but even these may be overcome. Birds migrate from one part of the globe to another either for breeding purposes or for climatic reasons; and the fishes and the whales disperse themselves through the seas and oceans according to the water that suits them best at the time.

Animal Distribution and Man.—The final word in the matter of change of home for both plants and animals is with man. Until the work of man in this respect began, the only other means of distribution beyond direct self-migration was chance carrying. Man's work seems to be the unconscious breaking-up of the natural regions and the breaking-down of all natural boundaries. He acts as the disturber of the natural order of things. Man destroys in any given area both animals and plants he does not want, *e.g.* the wolf in Great Britain, and many animals that he afterwards finds he does want, *e.g.* the bison * of North America and the dodo of Mauritius. On the other hand, he introduces plants and animals that he considers necessary for his own development and comfort, *e.g.* clover into New Zealand, pigs into the South Sea Islands, and the camel into Australia. Reversely he has introduced to other countries creatures and plants that have proved very destructive. Thus the house-sparrow has been acclimatised in the United States, Australia, and New Zealand, where it has become a serious pest ; the European rabbit has been introduced with dire results into Australia ; and the prickly pear (opuntia) of Virginia has done great damage in South Africa by overspreading and rendering nearly useless large tracts of country.

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* The true or mountain zebra is found (in fast diminishing numbers) in the mountainous regions of Central and South Africa. Burchell's and Grévy's zebras live in the open plains. The giraffe often resorts to forested regions for the sake of its food, but is precluded by its structure from permanent life in forests.

1. **The Palæarctic Region.**—The fauna and flora of the northern parts of this region have so many features in common with the corresponding parts of the Nearctic region that Professor Newton boldly merged them into one vast and continuous whole, to which he gave the name of Holarctic. It is admitted that some of the northerly forms in one region are represented in the other, but the southerly forms in the two regions differ greatly and are distinctive. This is why it seems better to treat these not as one region but as two.

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* The countless millions of bison that once roamed the prairies of North America, darkening the landscape and delaying the passage of railway trains, are now represented by a small herd jealously preserved in the famous Yellowstone Park, and by a few scattered bands in the remoter parts of the North-west Territories of Canada.

Among the forms common to both the Palæarctic and the Nearctic Regions the following may be cited as typical: the polar bear, the brown bear, the aurochs (*American:* bison), reindeer (*American:* caribou), elk (*American:* moose), wolf, Arctic fox, walrus, glutton (*American:* wolverine), lynx, beaver, lemming, sable, osprey, snowy owl, raven, willow grouse, etc. In the same way among the flora, the following trees, though differing slightly in variety, are found in both regions: the oak, beech, birch, elm, ash, fir, and maple.

But the following may be considered typical of the Palæarctic fauna: the Siberian tiger, otter, jerboa of the Mediterranean littoral, musk-deer, badger, yak (of Tibet), kiang or wild horse, camel, goat, hamster rat, mole, and rabbit. The birds are represented by the golden eagle, various kind of hawks, grouse, pheasants of many varieties, thrush, and starling. During the summer months the tundras of northern Siberia are the homes of vast hordes of birds, which, on the break-up of the ice, migrate thither from every quarter of the globe for the purpose of breeding.* Their numbers are countless, and they vary in size from the majestic wild swan to the unobtrusive willow-wren. The mosquito is so extremely abundant in the tundras during the summer as to be a perfect scourge.

Of the vegetation of the tundras, the following description is given by the ornithologist Seebohm: "The vegetation on the dry parts of the tundra was chiefly sedges, moss, and lichen, of which the familiar reindeer-moss was especially abundant. In some places there was an abundance of cranberries with last year's fruit still eatable, preserved by the frost and snow of winter. Here and there we met with a dwarf shrub, not unlike a rhododendron, a heath-like plant with a pale red flower, and dwarf birch running on the ground almost like ivy. The flat boggy places had evidently been shallow lakes a few weeks ago, after the sudden thaw, and were now black swamps, water in the middle, grown over with yellow-green moss, and sedges towards the edge. They were separated from each other by tussocky ridges of moor. We crossed the wettest bogs with impunity, seldom sinking more than a foot before reaching a good foundation, a solid pavement of ice."

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* As an instance of the wide range of these migrants the curlew sand-piper may be mentioned. This little bird, about the size of our skylark, breeds in northern Siberia, and in winter is found in such widely separated places as Australia, South Africa, and Patagonia. The turnstone is another well-known cosmopolitan.

Coming southward from the tundras we pass through the region of pine trees to that of the alder, ash, beech, birch, chestnut, elm, maple, oak, sycamore, and walnut. The pine-tree region, called also the **Taiga**, is by no means dense forest. There are many open spaces, both natural and artificial (the latter due mainly to devastation by forest fires), and in these clear spaces is to be found a wealth of berry-bearing bushes, such as bilberries, cranberries, crowberries, currants, raspberries, and whortleberries. The characteristic grains of the Taiga belt are rye and oats. The extreme south of the Palæarctic Region is the home of the myrtle, laurel, holm-oak, palm, and other evergreens. The subtropical fruits of the south are almonds, figs, grapes, and oranges. Apples, pears, cherries, and other temperate fruits also flourish in the south. Wheat, barley, and oats can be cultivated in parts of this region even up to the shores of the Arctic Ocean. Maize is one of the chief crops of the Balkan States, and such excellent crops of wheat are grown in the Hungarian plain that it is called the "granary of Europe." The

Black Lands of the Ukraine in South Russia are also celebrated as wheat-growing lands.

2. **The Nearctic Region.**—As has been said before, this region has many features in common with the Palæarctic; but there are several species which may be regarded as typical. Towards the north the musk-ox, jumping mouse, and the tree-porcupine are found; farther south these give way to the grizzly bear, black bear, puma, raccoon, prong-buck (the American "antelope"), prairie-dog, skunk, flying squirrel, and one marsupial,* the opossum. Like the tundras of Siberia, the northerly parts of this region (which are also tundra) afford a summer home to vast numbers of migratory birds, such as wild geese, waders and ducks of various kinds, divers, etc. Farther south, the birds typical of the region are the ruby-throated humming-bird, mocking-bird, blue jay, white-headed eagle (the national emblem of the United States), and the prairie-owl which shares the burrow of the prairie-dog. There is one typical reptile, the much dreaded rattlesnake.

The extreme northern flora is very limited within the Arctic Circle, reaching (in the "barren lands" of Canada) almost the zero of development; but even on the barren lands there is grass and reindeer-moss, berries, a sparse growth of stunted firs, willows, and birches, and in summer a profusion of brightly coloured flowers. Immediately south of the barren lands lies a Taiga belt. The middle-western parts produce some special forest trees, such as the giant Sequoia and Douglas pines. Round the Upper Mississippi basin and in the plains of Canada north of it, grows wheat, and the chief maize-belt of America stretches from 100° W. to 80° W. longitude, south of the

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* For a description of the marsupials, see under the Australian Region.

Great Lakes. Maize is the only grain indigenous to the region. In the south grow sugar-cane, yuccas, cotton, and tobacco, every one of which, except tobacco, is an importation from other regions. Oak, poplar, walnut, ebony, rosewood, mahogany, cedar, and other hard woods like the lignum vitæ of Mexico are common.

3. **The Neotropical Region.**—The flora of this region is particularly luxuriant, the fauna characteristic and varied. The larger quadrupeds are not plentiful, and the cat tribe is represented by the jaguar and the puma. The monkeys, generally known as spider-monkeys, are small and slender with long prehensile tails—a feature which distinguishes them from their relatives of the Old World. The llama,* vicuña, tapir, peccary, great ant-eater, armadillo, sloth, marmoset, maned wolf,† chinchilla, vampire-bat, and the capybara, the largest of living rodents, are characteristic of this region. Besides the opossums there is one other marsupial, the *raton runcho* or opossum-rat, of which at present very little is known. The birds of this region are remarkable either for their great size or for their gay plumage. Among them may be mentioned the great condor of the Andes (the largest of the birds of prey), the toucans with their unwieldy and brightly coloured bills, the rhea or American ostrich, blue and yellow macaws, the peculiar guacharo or oil-bird, the hoatzin, the prairie-owl (which, as in the north, shares the burrow of the vizcacha), and many species of humming-birds, all of brilliant metallic hues. To this

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* The llama (pronounced *yah-ma*) and the jaguar are the less powerful New World representatives of the Old World's camel and tiger.

† This creature is badly misnamed, for it is neither maned nor a wolf, but is a long-legged, long-eared dog (*Canis jubatus*).

region may also be attributed some of the penguins, the nearly extinct sea-elephant, and the sea-lions of the more southerly islands and coasts. The estuaries, rivers, and coasts of the Atlantic shores of this region are frequented by the curious aquatic mammal the manatee. In the rivers and lagoons, alligators, iguanas, and the anaconda or boa-constrictor, the mammoth among serpents, abound. Insect life is very abundant, the climate being for the most part hot and moist, and for the same reason the tropical plains have the most luxuriant vegetation of the world. The **llanos** of the Orinoco basin are vast grass plains enriched in colour by many kinds of beautiful flowers; the **selvas** are the densely wooded plains of the Amazon basin; the **pampas** towards the southern parts are only fairly luxuriant, and in that direction merge into the Patagonian Desert, grass gradually giving way to monster thistles. In the selvas and on the eastern plains there are jungles of palms, rubber trees, and tree-ferns, all matted together with lianas and ablaze with gorgeous orchids, while on the water-pools floats the gigantic victoria lily. In these eastern plains also are extensively cultivated coffee, bananas, and oranges; but these are all importations—coffee from the Ethiopian, and the other two from the Oriental region. The pine-apple is a native, as also are the cinchona (quinine), mahogany, and rosewood, which grow on the montaña or lower mountain-slopes that face the rain-bearing winds from the east.

4. **The Ethiopian Region.**—As this region is one of dry heat, it is favourable to the development of the largest species of mammals, though bears are entirely absent. The hippopotamus, gorilla, chimpanzee, giraffe, zebra, Cape buffalo, and the lately discovered okapi (a relative of the giraffe, but striped on the legs like a zebra)

are peculiar to this region. The other animals are the African elephant (to be distinguished from his Indian relative by his larger ears and greater size), rhinoceros, wart-hog, mandrill, the lemurs of Madagascar, the African manatee, and antelopes of various kinds, such as the eland, gnu, koodoo, and springbok. The antelopes vary in size from the eland, which is larger than an ox, to the little South African blue buck, which is smaller than a hare. The birds include the ostrich,* guinea-fowl, grey parrot, many kinds of weaver-bird, the remarkable shoebilled stork (*balœniceps*), and the flamingo, and amongst the reptiles are the crocodile and the puff-adder. As grass-eating animals abound, so also do the flesh-eaters which prey upon them, such as the lion, leopard, cheetah, hyena, jackal, and hunting dog. Camels, sheep, and oxen are importations. Among insects the tse-tse fly, whose bite is fatal to horses, oxen, and dogs, is the best known. South of the Sahara is a very wide belt of dense forest containing oil-palms, rubber trees, monkey-bread trees, baobabs, and many gum-producing trees. The southern part of the region is characterised by many kinds of heath-plant, aloes, fig-marigolds, geraniums, and proteas or "sugar bushes" on which the sun-birds (the humming-birds of the Old World) feed. Coffee is native to this region.

5. The Oriental Region.—This region has a very diversified fauna, and its flora is also abundant and interesting. In many ways it overlaps with both the Palæarctic and the Ethiopian regions, and many of its animals are common to the one or the other. Like the Ethiopian, this region produces the lion, jackal, hyena, cheetah, rhinoceros, etc., but the most characteristic animals are the Bengal tiger and the Malayan tapir.* In this region, too, are to be found the anthropoid apes (the orang-outang and the gibbons), the Indian elephant, buffalo, wild horse, several varieties of deer, and the camel which has Asia for its true home. In Borneo is found the *wah-wah*, which, though inhabiting forest country, is the only monkey in the world that cannot climb a tree. Living in the shallow seas and estuaries of the Indian Ocean is the dugong, a relative of the manatee. Among the more characteristic birds may be mentioned pheasants, peacocks, hornbills, ground-thrushes, and the jungle-fowl (which resemble in most details their descendants, our common domestic poultry). Vultures and kites, too, are common, and perform the office of scavengers. The hooded cobra and the crocodile are the most typical reptiles. The chief of the characteristic plants and trees of this region are arrowroot (which grows equally well in the West Indies), bananas (now extensively grown in all tropical countries), yams, rice, tea, ginger, coffee (an importation from the Ethiopian region), coconuts, bamboo, sandalwood, teak, and ebony. Of all the regions of the world the Oriental has been the most useful to man. With the exception of maize it has produced for him every useful grain, and fruits such as the pear, apple, plum, cherry, peach, and apricot are of oriental origin. Asia is also the original home of all our domestic animals, with the exception perhaps of the dog.

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* The majority in this region are domesticated in South Africa for the sake of their feathers.

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* The occurrence of tapirs in such widely separated places as South America and Malay is interesting. It is a case of what is known as "discontinuous distribution." Assuming that the same species of plant or animal originates but once, it follows that if the same species occurs on both sides of an impassable barrier, the species has been in existence longer than the barrier, and though now discontinuously distributed, the species must have formerly been continuously distributed.

6. **The Australian Region.**—This region, with regard to its mammalian fauna, is quite unlike any other. Nearly all the animals are marsupials—a type of mammal which at one time extended throughout the whole world, but which, with two exceptions, has found its last stronghold in this region. There are several kinds of the marsupials—herbivorous like the kangaroo and the phalangers (commonly known as opossums); omnivorous like the bandicoots; carnivorous like the Tasmanian wolf and the Tasmanian devil. But perhaps the strangest of all are the echidna and the duck-bill (*ornithorhynchus*) or platypus, which lay eggs and also suckle their young. They form a connecting-link between the mammals and the reptiles and amphibians. The most typical animals that are not marsupial are the dingo or Australian wild dog, the babirusa (a wild pig from Celebes), and lemurs. Birds are represented by the birds-of-paradise, cockatoos, lyre-birds, bower-birds, emus, cassowaries, kingfishers, and doves remarkable for the great beauty of their coloration. The ceratodus or mud-fish, which breathes by means of both gills and lungs, is the oldest form of fish known to science, having come down to us unaltered from Mesozoic times. This extraordinary creature is one of the best instances of discontinuous distribution, since the related species exist at such widely separated points as Africa, South America, and Australia. Typical Australian flora includes the various species of eucalyptus or "gum-tree" (like the blue-gum, red-gum, stringy bark), the jarrah or Swan River mahogany, yellow-blossomed acacias or wattles, and the gorgeous flame-trees of the eastern highlands. Bread-fruits and spices of various kinds are common in the north of the region.

7. The New Zealand Region.—This region is as strongly divided from the Australian region both positively and negatively as that is from the Oriental. Its isolation from the rest of the land-world must have most likely occurred before the appearance of terrestrial mammals, as none except a species of bat were originally found anywhere in this region. Seals of various kinds abound along the rocky coasts and round the numerous islands. The region is peculiar in possessing two flightless birds, the weka-rail and the better-known apteryx or kiwi. Another typical bird is the kea-parrot, which has taken to killing sheep by pecking the flesh of the loins. Among the most important timber trees is the kauri pine, which is valuable both for its timber and resin. A plant peculiar to the region is the so-called New Zealand flax, which really belongs to the lily tribe. Ferns and wonderful fern-trees abound, and fruit trees of the temperate zone thrive well.

The Botanical Zones.—Speaking generally, vegetation is most rank and luxuriant within the tropics, where conditions of heat and moisture are most largely present, and diminishes in variety and abundance from the equator to the poles, where the zero of both plant and animal existence is reached. There is the same diminution in the direction of altitude, starting from the base of a mountain at the equator. Thus in Switzerland the vegetation may begin at the foot of a mountain with the vine—a plant of the hot temperate region—and ascend through successive stages of deciduous trees, grains, coniferous trees, rhododendrons, mosses, and small shrubs of the Alpine region, till the glacier line is reached where vegetation ceases (see fig. 62, p. 209).

The space between the equator and the poles was divided by Baron Humboldt, one of the world's greatest

Latitude.	Name of Zone.	Equivalent Elevation in feet.	Mean Annual Isotherms, F.	Characteristic Vegetation.
0°–15° N. & S.	Equatorial .	Sea-level—2,000	82°—78°	Palms, bananas, spices
15°–25° N. 15°–23½° S.	Tropical . .	2,000—4,000	78°—73°	Figs, tree-ferns, sugar-cane, bamboo
25°–35° N. 23½°–30° S.	Sub-tropical .	4,000—6,000	73°—68°	Myrtles, laurels, acacias, and trees with thick shining leaves, cotton, tea, orange, vine, olive
35°–45° N. 30°–40° S.	Warm temperate	6,000—8,000	68°—60°	Evergreen trees, maize, rice, orange, vine, indigo
45°–58° N. 40° southwards	Cold temperate .	8,000—10,500	60°—48°	Trees with deciduous foliage, cereals, hemp, flax
58°–66½° N.	Sub-arctic .	10,500—12,500	48°—40°	Pine, fir, beech, cypress (conifers), barley, oats
66½°–72° N.	Arctic . .	12,500—14,800	40°—32°	Lichens, dwarf willows, birch, and hardy shrubs
72°–90° N.	Polar . .	14,800—snowline	below zero	Mosses and alpine plants

naturalists, into climate zones at sea-level. With these horizontal belts, corresponding vertical belts have been estimated, and in the table on the opposite page are given the results.

The Fisheries of the World.—In the great fishing-grounds of the world only those forms of marine life are harvested that give something towards the use and convenience of man. Though seals, walruses, whales, and other cetaceans are not truly fishes, their capture is generally spoken of as seal-fishing, walrus-fishing, whale-fishing, etc. Human geography takes the whole of marine, river, and lake life, and divides it into two classes, useful and non-useful. The useful forms include the edible, such as herring, cod, salmon, oyster, shrimp; the oil-bearing, such as the whale, porpoise, walrus, seal; the fur-bearing, such as the sea-bears and the fur-seals; the hide-bearing, such as the sea-elephant and the porpoise; and the ivory-bearing, such as the narhwal and the walrus. Except for sport and pleasure fishing, together with a little research fishing done in the open ocean, all the chief fisheries of the world are carried on in the shallow waters near the coasts of the continents and islands, *i.e.* upon the continental shelf (p. 324). The fish fauna found in the open ocean either require sunlight but are independent of a resting-bed, and so live near the surface; or they are independent of sunlight but require a resting-bed, and so live down in the ocean abyss. The fish fauna that live in the shallow waters near the coast (including those water-animals that live partly on land, such as seals, etc.) are those that require both sunlight and a resting-bed. The West European fisheries are carried on in all parts of the North Sea, and along the western shores of the British Isles and Norway. The chief fishes taken are cod, herring, and mackerel. Other kinds are crabs,* lobsters, shrimps, oysters (from cultivated beds), and many kinds of flat fish like soles, turbot, plaice, and halibut. In the Baltic Sea the herring and the sprat fisheries are the most important, the young herrings and the sprats being largely preserved as "anchovies" and "sardines." † The Mediterranean fisheries are chiefly concerned with tunny (the chief of the mackerel family), sardines, anchovies, and mullet; but in the Levant at the eastern end, coral and sponge fishing are very valuable. The Canadian, the Newfoundland, and the Labrador fisheries are the most extensive in the world. The most important of the fish caught are cod, lobsters, herrings, and mackerel. Most of the lobsters (as well as the salmon caught in the rivers and lakes) are canned for export. Sealing for the "hair seal," valuable for its hide and blubber, is carried on along the coasts of Labrador and Newfoundland, and in the Bering Sea there are extensive fisheries of the "fur seal." In the United States, the New England fisheries are very rich in oysters and clams among shellfish, and in cod, shad (a kind of herring), mackerel, lobster (twice the size of the British lobster), haddock, and halibut. The tropical coasts of the Atlantic are the home of the green turtle, whose flesh and the broth of whose flesh is so much esteemed.‡ The absence of an extensive continental shelf in the eastern Pacific accounts for the lack of fishing-grounds of any great importance.

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* Besides the swimming crabs such as are found round the British coasts and in the China and Japan Seas, there are in the West Indies and other parts of the tropics land crabs, which, if caught as they come down from the hills to deposit their eggs, form a very great delicacy.

† The name sardine has no scientific value. It simply denotes a small fish, generally of the clupeoid (herring) kind, preserved in oil. The best sort of "sardine" is a small pilchard.

‡ Mock turtle is made from calves' heads.

The Western Pacific, however, with an ample continental shelf, has good fishing-grounds, especially in the Sea of Okhotsk, the China Seas, and in Japanese waters. The chief fishes caught are herrings, sardines, crabs, and mackerel; while oysters, turtles, and lobsters are cultivated on the shores of Japan. Farther south, in the East Indian and Australian waters, herrings, mackerel, king-fish, oysters, crayfish, and prawns are the chief fishes taken. In North and West Australian waters is carried on the most important of the Australian fisheries, that for pearls and pearl-shell.* On the Agulhas Bank south of the Cape of Good Hope is a fishing-ground specially prolific in soles and crayfish, and from this colony tinned crayfish is becoming a more important export every year.

Besides these sea fisheries there are several important and valuable lake and river fisheries. Of these the most important is the salmon fishery.† This is carried on in the North American rivers of the West Atlantic, and also in the rivers of Norway, Iceland, and the British Isles. But incomparably the richest wealth of salmon is found in the rivers of the Northern Pacific, both on the east and on the west. The rivers of Alaska and British Columbia are especially prolific, and in Kamschatka the abundance of the fish is such that they sometimes stop the course of the rivers and cause them to overflow their banks. The rivers and lakes round the Canadian Lake Peninsula abound in salmon-trout, speckled trout, and the delicious "white-fish," which is the principal feature of the Canadian Lake fishery. Among other fresh-water fisheries that of the sturgeon * of the Caspian, of the Black Sea, of the Danube and the rivers of South Russia, of the Great Lakes of North America, and of the east coast of Siberia is important. The Caspian and the Great Lakes of North America are also the seat of an important herring fishery (the herrings of the Great Lakes being, of course, of the fresh-water kind). In most of the slow rivers of Europe the eel is a common fish. The carp family of fresh-water fish, which includes barbel, bream, gudgeon, dace, roach, chub, etc., although plentiful in most of the rivers of the northern hemisphere and affording sport and recreation to anglers, do not add much to the world's food-supply.

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* The other great pearl fisheries of the world are carried on in the Persian Gulf, in Ceylon waters, and round Madagascar.

† Although the salmon fishery is spoken of as a river fishery, it must be noted that at certain seasons of the year it is also a sea fishery near the mouths of rivers.

The fishing-grounds for the larger sea-mammals are mostly in the extreme northern and southern waters. The Greenland or Arctic right whale has its home in all latitudes higher than 60° N., and the southern right whale has its home in the corresponding waters of the south. The rorqual, longer and thinner than the Greenland, inhabiting the same waters though somewhat farther south, is much less valuable for whalebone and oil. The sperm-whale or cachalot is a toothed whale (not a whalebone producer) and is found in most tropical and sub-tropical seas. Of the remaining sea-mammals (cetaceans), the dolphin occurs in all seas and sometimes even in rivers, the porpoise and the grampus (or killer-whale) are also found in all seas from Greenland to Tasmania, the porpoise being the most familiar on the British coasts. The common oil-seal is found in the Arctic north of Eurasia, on American shores as far south as 40° N., in the Caspian and in the Sea of Aral. A tropical species, the monk-seal, is found in the West Indies and on the

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* The flesh of the sturgeon is pleasantly edible. From the air-bladder isinglass is made, and from the roe caviare.

North African coasts. The true fur-seal and the sea-otter (both fur-bearing mammals) are now confined to the North Pacific. The walrus occurs in the Arctic Seas and the North Pacific, the sea-elephant in the Antarctic ice-fields and islands. The porpoise, grampus, and the walrus yield, besides oil, a very valuable hide for leather. The sea-bears have a soft, delicate fur as highly valued in commerce as seal fur; sea-lions have a hairy skin and therefore yield no fur. Two marine mammals, the manatee and the dugong, are the sole survivors of a large family known as the sea-cow family, all the members of which were valuable for their oil and hides. The manatee is found on both sides of the tropical Atlantic, and in the Amazon and the Orinoco Rivers. The dugong is found in the tropical Indian Ocean, and on the West Australian coast dugong fishing is practised as a regular industry. The flesh of both these mammals is of excellent quality and flavour (see p. 326).

Exercises

1. Show by examples that the distribution of animals on the earth's surface is not simply dependent upon climate.
2 Give examples to show that transport of flora and fauna to new regions may sometimes be a blessing and sometimes the reverse.
3. What conditions are necessary for the successful cultivation of root crops, tea, vine, wheat, rice, and flax? Why are there so few (about 4,000,000) sheep in Ireland?
4. Of what biological regions are the following plants and animals characteristic?—crocodile, oil-palm, chestnut, condor, cinchona, rattlesnake, bird-of-

paradise, hippopotamus, eucalyptus, ginger, coffee, reindeer.

5. Name the great timber-producing regions of the world, stating the sort of timber grown in each. (Oxf. Jun. Loc.)
6. State in what part of the world the following are found, and for what purpose they are used: Bananas, cacao, esparto-grass, india-rubber, oil-palm, olive, reindeer-moss, sugar-beet, sugar-cane.
7. By what causes are the vegetable productions of a country determined? Illustrate by reference to cocoa, coffee, copra, currants, rubber, sago, stating carefully what they are. (Oxf. Sen. Loc.)
8. How would you subdivide the land of the eastern hemisphere into regions characterised by peculiar assemblages of terrestrial animals? How can the distribution of such animals be any guide as to the past history of land and sea? (Oxf. Sen. Loc.)
9. Describe and explain the characteristic vegetation of *either* the countries bordering upon the Mediterranean *or* that part of North America between the 100th meridian of west longitude and the Rocky Mountains. (Civil Service.)
10. Some pastoral districts are situated in natural grass regions, others in clearings of temperate forests. Give an example of each of these and compare the general conditions. (Oxf. and Camb. Sch. Cert.)
11. Give an account of the changes in vegetation you would expect to see during the ascent of a tropical mountain from sea-level to the snow-line. Describe any part of such changes which may be seen in the British Isles. (Oxf. and Camb. Lower Cert.)

12. Where are forests found in the north temperate zone ? What climatic conditions are necessary for their growth ? (Oxf. and Camb. Lower Cert.)
13. What are the essential conditions of forest growth ? What are the important differences between temperate and tropical conditions ? (Lond. Univ. Inter. Science.)
14. How far are the expressions "temperate fauna," "tropical flora," correct—*i.e.* does identity of latitude with similarity of climate imply agreement in the character of the flora and fauna ? Give examples.
15. Write a short account of the world's fisheries. Account for the fact that most of the fishing-grounds are near the continents and not in mid-ocean.
16. What parts of the Old World are grass lands ? Account for this. Point out the differences between the grass lands of Europe and Africa. (Oxf. and Camb. Sch. Cert.)
17. Describe the different kinds of vegetation that exist in Canada, state where each is found, and give as full explanations as you can of this distribution. (Oxf. and Camb. Sch. Cert.)
18. Describe and explain the distribution of grass lands in Africa. (Oxf. and Camb. Sch. Cert.)
19. Describe and account for the position of the great forest belt in Siberia. What kinds of trees are commonly found in the different parts of this belt ? (Oxf. Sen. Loc.)
20. Give two examples of important cultivated crops which are grown only in the tropics, describing the kind of climate which favours each, and naming a region in which each is produced. (Oxf. Jun. Loc.)

21. Describe the conditions suitable to the growth of (*a*) maize, (*b*) rice. Give examples (one for each) of regions where these crops are extensively cultivated, and explain in each case the geographical reasons which make the regions suitable. (Oxf. Jun. Loc.)
22. Analyse and discuss the climatic conditions which give rise to the occurrence of (*a*) evergreen, and (*b*) deciduous forests. Apply your answer to account for the distribution of such forests in Europe. (Civil Service.)
23. Enumerate very briefly the chief character of the type of forest found in equatorial and neighbouring regions, and also the climatic conditions which favour its existence. Name localities between the tropics where such forests are not found, and in each case say why they are not found in that district. (Civil Service.)
24. Describe the vegetation of (*a*) tundra, (*b*) steppes, and describe the conditions of life of the inhabitants. Where are such districts to be found? (College of Preceptors.)
25. Explain carefully the phrase *tropical products* and name six of the most important. (Oxf. Jun. Loc.)
26. How are the successive belts of vegetation arranged on the west coast of Africa? Account for their character and distribution. (Lond. Univ. Matric.)

CHAPTER XXXIII

Races of Mankind

Origin.—The word *races* is used to designate those distinct physical types of mankind, from the intermingling of which are developed peoples and nations. Man, having a jointed backbone, is called a vertebrate animal. He has characteristics similar to other vertebrates, but is so completely separated from the rest as to require special consideration. The larger anthropoid apes, like the gorilla, the chimpanzee, and the orang-outang, have a jointed backbone, a spinal nerve cord, and a brain, and they all suckle their young. So far as this goes, man has precisely the same organs and the same habits. But though the normal human brain is twice as heavy as the brain of a chimpanzee, there is not so much difference between man's brain and a monkey's brain as there is between the brain of a chimpanzee and that of a Madagascar monkey. All races of animals, higher as well as lower, have been evolved from a common ancestor ; and all the different races of men are but varieties of one single stock. The two extremes of the human species are the most highly developed and cultivated man at the one end, and the lowest savage at the other, both of whom have sprung from the same remote source ; but the physical differences between the one extreme and the other are so great that there is a much wider gulf between them than between the lowest savage and a gorilla. The difference between man and the lower animals is that man possesses what may be called **human attributes,** such as reasoning power, power of language, power of using previous experience, power of controlling conduct, sense of religious duty, and the like. The more of these in number and degree, the more human or distinctly man will the creature be; the less of these in number and degree, the less human or distinctly man. It is possible that the highest of the higher animals, *i.e.* the anthropoid apes, and man had a common ancestor, but at present there is no definite knowledge of man's pre-human ancestors. Apart from what may be called the introduction of new causes, the course of evolution was probably in the following order. First there would be developed on the part of these ancestors an instinctive desire to protect the young and weak. This desire would by means of accelerated variety of type make for greater differentiation, followed by fixture of advantageous variations. The best types naturally developed the best brains, and so further intensified existing progressive types. Lastly, differentiation was complete when, by the assumption of the erect position, the hands were set free to be instruments for the still developing brain. The first stage of human culture, usually spoken of as the **Old Stone and Shell Age,*** takes for granted this general human type, from which, during a period of many thousands of years, were gradually evolved the four main divisions or groups of the race. During this stage the primitive man spread in all directions from the warm alluvial valleys of southern Asia and north-eastern Africa. It is significant that the existing specimens of weapons and implements belonging to this age, crude and rough as they are, do not suggest the handicraft of beginners, but rather the work of men behind whom lay a long history. Later came the stage called the **New Stone** (the Neolithic) **Age,** during which the four main types became fully established, made considerable progress, and drifted into more or less definite geographical centres in the temperate regions, thence afterwards to spread over the world. The migrations, sometimes hostile, sometimes friendly, soon became continuous, and resulted in fresh race groupings and modifications.

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* It should always be remembered that the various "ages" into which the history of man is divided (the Old Stone Age or Palæolithic, the New Stone Age or Neolithic, etc.) mark stages of development rather than chronological periods. At all times these ages overlapped as they do to-day, when among the savages of Australia and South America you meet with Stone Age peoples living near civilised or "Iron Age" peoples.

> "When we reflect on the many geographical changes that man has witnessed—the submergence and re-elevation of enormous tracts—the erosion of valleys and general lowering of the surface by denudation; when we consider that he has lived through a succession of stupendous climatic revolutions; that he has seen widely contrasted floras and faunas alternately occupying our continent—tundras, steppes, and great forests succeeding each other again and again—we must feel convinced that the few thousand years that have elapsed since the downfall of Babylonian, Assyrian, and Egyptian Empires are as nothing compared with the long æons that separate the earliest times of history from the apparition of Palæolithic man in Europe."—Prof. J. Geikie in *Antiquity of Man in Europe.*

Race Development.—Whatever modifications in type have taken place, there is really only one human species. Race development signifies the acquirement of distinguishing physical qualifications by means of life spent continuously under varying conditions of geography, climate, food, exercise, and habits. Clothing modifies the colour of the skin; the carriage of the body and the general set of the bony framework are influenced by habits of posture; the shape of the skull and the expression of the countenance change with the cultivation and development of "self-given endowments," which owe their origin to the new demands of changing circumstances. But the most important factor is latitude. "Character is a function of latitude." Within the tropics, man, because he was man, though a savage, was superior in intelligence, skill, and cunning to all other living creatures. But his mastery cost him so little effort, and he found his livelihood so easy to secure,* that his advance was not so rapid as that of those who found themselves placed amid the greater difficulties of the temperate zones. In these temperate zones, because constant effort was necessary, intelligence, skill, and cunning were better and more quickly developed. Therefore, men of these regions by degrees outdistanced and became the masters of not only other races of men, but also even of Nature herself. In Arctic regions, the struggle of man against cold and starvation was too severe; there so little opportunity occurred for proving the predominance of one race among many; there, if man wished to survive, he must prove his ability to rise superior to conditions of life almost inhuman; there very much effort brought proportionally so minute results, that development was not more rapid than in the tropics. So, nature, in the tropics too kind, and in the polar regions too cruel, was at her best in regions that lay between. The first struggle of race-groups against physical and animal environment being over, settlements by family and tribal groupings commenced, and then followed a new form of struggle—between group and group. This later form of struggle, though involving much apparent cruelty, did more than anything else for development. Some groups, finding themselves isolated by geographical barriers of mountain, sea, or desert, were concerned in no such struggles, and remained stationary, or even became retrogressive. Eventual contact of such a stagnant and backward group with a more highly specialised group always meant the elimination and extinction of the former. The rapid extermination—not always an extermination by violence—of the Indian in North America is a case in point. The destruction of the bison, his chief food, aided in his disappearance ; but in all cases where savagery is brought into contact with highly specialised civilisation, savagery will disappear.

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* Even now in some tropical regions, in West Africa for example, there is a saying that one only needs "to tickle the ground with a hoe for it to laugh with a harvest." The banana among savages, being so easy to cultivate and so extraordinarily prolific, is a great obstacle to civilisation, because the fertility of the tropics reduces necessity for effort to a minimum.

The Four Races.—The classification of the human species into four races is based upon such features as colour of skin, colour and quality of hair, shape of skull, form of bones, etc. Broca's *Table of Colours* recognises thirty-four shades of colour in the human skin. All of them, however, may be regarded as variations of **four chief colours,** white, yellow, brown, and black, which give the names to the four chief races of mankind. But colour of skin is by no means the only characteristic feature of the races, nor is it even the most constant. Other features to be noted in classification are : (1) the shape of the head, whether long as in the Negro, short as in the Mongol, or intermediate as in the Iberian ; (2) the shape of the jaws, whether projecting as in all dark races, or straight as in the white and yellow races ; (3) the colour and texture of the hair, whether black and curly, black and smooth, black and woolly, brown and wavy, red and curly, and so forth.

The White Race.—This is also called **Caucasian.** The hair is of all shades, varying from black, through brown, red, or golden, to flaxen ; it may be either straight, wavy, or curly. The skin is nearly as variable as the hair. It may be even blackish (as in the case of Hindus and Egyptians), it is frequently brown or swarthy, sometimes pale, but usually florid. The jaws are straight and small, the cheek-bones are also small, the nose is straight or arched, and though large is narrow. The eyes are always straight, and vary in colour from black, through brown, green, or blue, to light grey. In temperament this race varies from the seriousness and stolidity of the northern varieties to the impulsiveness and inconstancy of the southern.* As a race, all are active and enterprising, and everywhere highly developed. To this race belong the Egyptians and all African tribes living north of 10° north latitude ; the Jew, the Arab, the Afghan, and the Baluchi ; the Hindu, the Persian, and the Armenian ; and in Europe, the Keltic, the Romanic, the Greek, the Teutonic, and the Slav peoples. The chief representatives of the Keltic peoples (all pushed away into the western corner of Europe) are the Irish, the Scotch Highlanders, the inhabitants of the Isle of Man, the Welsh, the people of Cornwall and Cumberland, and the Bretons of Brittany. The Romanic nations are the French,† the

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* Very striking race-contrasts can be found even in the same country. Thus the northern Italian is thrifty, hardworking, and enterprising (it was largely with northern Italian labour that the Forth Bridge was built) ; but the southern Italian is thriftless, lazy, and aimless.

† The French, like ourselves, are a very composite people, being made up of Romanic, Keltic, and (to a small extent) Teutonic elements.

Italians, Portuguese, Spanish, Roumanians, and Walloons of Belgium. With the Greeks go the Albanians. The Teutonic group includes the Scandinavians, Icelanders, Dutch, Germans, the Flemings of Belgium, the Swiss, and most of the inhabitants of the British Isles. In the Slav group are counted the Russians, the Czechs of Bohemia, the Poles, and the peoples of Bulgaria, Servia, and Montenegro.

The Yellow Race.—This is also called the **Mongolian.** The hair is coarse, smooth, straight, and dull black. The skin is a dirty yellow, brownish in the case of the Malays. The jaws are straight and slightly projecting, the cheekbones high and laterally prominent, the nose small and usually slightly tip-tilted. The eyes are small, black, and oblique. In temperament this race is sluggish and sullen, has little initiative, a low moral standard,* but great powers of endurance, is frugal, thrifty, and only moderately developed. To it belong the Mongolians, Manchurians, Siberians, Tartars, Turks, Magyars (Hungarians), Finns, Lapps, Koreans, Japanese, Tibetans, Chinese, Burmese, Siamese, Malays, many of the Polynesians (some Polynesian peoples, *e.g.* the Hawaiians and the Samoans, are believed to belong to the white race), and the Malagasies of Madagascar.

The Brown Race.—This is also called the **American.** The hair is exactly like that of the yellow race. The skin is coppery, yellowish, and various shades of brown. The jaws are massive and somewhat projecting, the cheekbones are moderately prominent, the nose is arched, large, and rather narrow. The eyes are small, straight, black, and rather sunken. In temperament the race is moody, taciturn, wary, impassive, and only moderately developed. To this race belong the Eskimos, all the so-called Red

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* From a Western standpoint.

Indian tribes, the Aztecs, Incas, and other native tribes of Mexico and Central America, Caribbeans, Patagonians, Fuegians, and all native tribes of South America.

The Black Race.—This is also called the **Negro** race. The hair is short, jet black, and woolly. The skin is a very dark brown or blackish. The jaws are projecting, the cheekbones small and slightly retreating, the nose flat, small, and broad at the base. The eyes are large, round, black, and prominent. In temperament this race is indolent, improvident, fitful, with a small sense of dignity, generally of low moral character, and only slightly developed. To the race belong all the Sudanese and Bantu tribes of Central, East, West, and South Africa. The oceanic branch of the race includes the Papuans, the Fijians, the extinct aborigines of Tasmania, and the aborigines of Australia. The Hottentots and Bushmen of South Africa, the Akkas and the Batwas of Central Africa (the smallest race known), the natives of the Andaman Islands, and the Aetas of the Philippines are of the so-called Negrito or "little negro" type, and may possibly represent the aboriginal element in those regions.

Civilisation and Barbarism.—The population of the earth is approximately 1,500 millions, of which six-sevenths are civilised; the other seventh belongs to the lower or barbarous orders of mankind. This division coincides with that between nations that have some recorded history and those that have none. The first distribution of man was probably by belts or zones, divided from one another by some strongly marked physical feature, in which zones the separated races became marked by distinct characteristics, passing from the lowest depths of savagery through certain well-defined stages towards a state of culture and civilisation. First the savage hunted his prey-food by his own unaided cunning, later he trained other animals (the dog for instance) to assist him *: this stage may be called the **hunting stage.** Next, now much less savage, he domesticated such animals as sheep and oxen, and followed the migrations of his flocks as they moved from one pasture to another: this may be called the **nomad stage.** Later, he tamed and domesticated the horse, and with this for a beast of burden and the ox for ploughing, he became a settled agriculturist. This may be called the **agricultural stage.** The invention of machinery—worked by simple hand-levers, by wind-wheels, or by water-wheels—laid the foundation for the rapid development that followed upon the introduction of steam as a motive power. This may be called the **industrial stage.** In all later stages of development there may be found traces of all the former stages. During the nomad stage man began to develop means of transport; and with the progress of civilisation transport became easier and easier, until rivers ceased to be impassable, then the barrier of mountains was overcome, and lastly even seas and oceans. Therefore, to every race comes a stage in the process of development when natural barriers may be surmounted. If the opportunity is seized and used, civilisation continues; if not, then civilisation is checked for races content to remain confined by these barriers.† It was during the times when mountains, rivers, and seas constituted serious difficulties to travel that what are called *natural boundaries* were fixed. And not till these were to some extent conquered could men be anything but slaves to their environment. The progress of civilisation means a combination of many lines of progress. It is progress in civilisation when there come into existence possessions of the community as distinct from possessions of the individual; when commerce becomes the scientific interchange of different regional commodities; when the outcome of man's natural impulse to play and imitate is found in music, dancing, acting, and painting; when rattling and drumming give way to concerted, tuneful music; when rude scratched drawings give way to painting and sculpture; or even when picture-writing gives way to the use of an alphabet.

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* The hunting leopard or cheetah in India, and the otter and the cormorant in China, are still used for the same purpose, as was (and still is to a small extent in Europe and Asia) the falcon. Falconry is now chiefly practised in East Central Asia.

† Abundant evidence remains to this day of the effect of mountain ranges as barriers to intercourse. The republic of Andorra in the Pyrenees has preserved its independence for many centuries because of its inaccessibility; Spain and France have remained two distinct nations because of the Pyrenees; the Tibetans in Asia are a further example; and so on.

Physical Conditions and Race Development.—Similar geographical conditions tend to develop similar modes of life even among different races of mankind. In the **cold deserts** of the world agriculture is always impossible, because they are nearly rainless, and the inhabitants are and must remain nomadic hunters. They are nomadic since they must follow their herds of reindeer as they move from one feeding-ground to another; they are fishermen and hunters because flesh is almost their sole article of diet, and skins their sole article of clothing. Modern commercial enterprise has to a small extent brought to these nomadic peoples some taste of vegetable foods such as coffee, tea, tobacco, and alcohol. In return for these luxuries furs are exchanged.

In the **hot deserts** the population is partly nomadic and partly settled. The settled population is to be found in the oases, where caravans call to trade in dates and salt. Small industries of pottery and leather manufacture are sometimes found in the villages of the oases, and in towns of the western Sudan like Kano, the great Hausa capital, important manufactures of cotton have even sprung up. Across the Sahara caravans carry cargoes of ivory, cotton, oil-seeds, ostrich feathers, and spices from the fertile central regions of the Sudan to the Mediterranean seaboard; and in the same way trade is carried on across the Asiatic deserts, where the staple of trade is principally "brick-tea" (from China), furs, and salt (from Siberia). Most of the desert inhabitants are expert robbers, notable instances being the Tuareks of the Sahara and the Turcomans of Central Asia.

On the **grass lands** of the world, where rain is on the whole scanty, the steppes, savannahs, etc., stock breeding is the chief occupation. The dwellers on these lands, especially on the Asiatic steppes, depend for all the necessaries of life upon their flocks and herds. From them they obtain wool or hair for tent coverings, clothing, rugs, and carpets; hides and leather for saddlery, footwear, and bottles; milk for drink; butter and cheese for food. The nomads of these steppes are proud, independent, extremely conservative, and generally of a type higher than the nomads of the frozen or the hot deserts. The pastoral inhabitants of the African savannahs live a settled and less primitive life than the dwellers on the Asiatic steppes. On the Australian and the American grass lands the people are settlers who have established large cattle- and sheep-runs (Australia) and cattle-ranches (America). From these a great trade is carried on in wool, hides, meat, and tallow.

In the uncleared **forest lands of the temperate zones,** such as those of Canada and Siberia, the chief occupations are those of hunting, fishing, and lumbering. Most of the lumbermen work in the forests only in the winter, and return to town or farm life at the end of the lumbering season.

As soon as the forest land is effectively cleared, **agriculture** commences, permanent settled life becomes the rule, industries connected with farm work rapidly develop, and there is a general advance along lines of scientific industry, and appreciation of the comforts of domestic life and enjoyment.

In the solemn, silent, and gloomy **tropical forests** the luxuriant growth of plant life leaves little favourable opportunities for either human settlement or human development. Clearings are made by explorers and visiting hunters only with the greatest difficulty in the dense, dark, and inter-tangled forest growth. The native races of the African forests are black dwarfs seldom exceeding 4 feet in height, and known as the Pygmies. They neither make clearings nor cultivate the ground.* They are essentially hunters, and have a thorough knowledge of forest life—especially a knowledge of vegetable poisons. This knowledge they make use of in the manufacture of poisoned arrows, and because of their unerring skill with these, they are very formidable enemies to all but the white man. Other forest tribes live on the edge of the forest lands, where maize, potatoes, bananas, and yams are grown by the women. To these outskirt dwellers the pygmies bring hides, ivory, and vegetable poisons, and exchange them for bananas, knives, and tobacco. These fringe tribes of the tropical forest make their clearings by setting the forest on fire, and either cultivate the land and grow produce for barter, or gather rubber, resin, and other tropical products for the same purpose. In the Brazilian

* This is not true of the Pygmies of Uganda.

tropical forest many clearings have been made on which are grown such crops as coffee, cocoa, sugar-cane, manioc (from which tapioca * is made), rice, and tobacco. The natives of the remote interior collect and sell to visiting traders such products as native rubber,† sarsaparilla, and Brazil nuts. There are tribes in the forests of the Amazon that in appearance and development correspond exactly with the pygmies of Central Africa.

Density of Population.—The thinly peopled districts of the world are naturally those where hunting is the chief occupation of the inhabitants; for wild animals do not live where there are many people, nor where vegetation is either non-existent or so dense and dank as to discourage the higher forms of animal life. These regions are the frozen deserts, the hot deserts, and the tropical forests. There were, for instance, very few people on the Great Plains of North America, when the red-man and the buffalo had these regions to themselves; there were no people at all in the howling desert of Atacama in South America till Europeans went there to get nitrate of soda; the Amazonian forests have but the merest sprinkling of savage inhabitants; and in our own country the grouse-moors and the so-called deer-forests ‡ of Scotland never have, and never could have, sustained any considerable number of inhabitants. In pastoral regions the population is denser than in the hunting regions, and in agricultural regions, for obvious reasons,

* The inferior pearl tapioca sold in shops is not the product of the manioc root, but is made from potatoes.

† Native rubber is considered by many traders to be far superior to the rubber obtained from cultivated plantations.

‡ A deer-forest is not a forest of trees. It is in most cases bare hillside where not a tree is to be seen. The word "forest" originally meant an unenclosed stretch of ground over which the rights of chase were reserved.

it must be denser still. A mountainous country is more suited to pastoral occupations than to agriculture, which is best carried on in valleys and lowlands. Hence valleys and lowlands will bear a denser population than very hilly and mountainous districts. Contrast, for example, the sheep-walks of the Scottish Highlands with the carefully farmed lowlands of the Lothians. In long-settled countries, where to agricultural development has been added the discovery, the securing, and application of mineral wealth, the population reaches almost a maximum density. The coal- and iron-fields of Great Britain and of the eastern United States are examples of this. Density of population is reckoned by the average number of people living on each square mile of available land. London has 36,000 persons to the square mile. The density of England as a whole is over 668 to the square mile, Scotland 160, Ireland 136, and Wales 273. Norway has the scantiest population of any European country (11 to the square mile), England the densest; next to England is industrial Belgium with 660, and next to Norway are Sweden with 31 and Russia-in-Europe with 69. This is what we should expect from the physical character and human occupations of the last three countries; for Norway is very mountainous and is a fishing-country; Sweden, except in the south, is also hilly, and its predominant industries are connected with forests which do not require many hands; while the huge flat stretches of Russia, where little rain falls, favour the pastoral industry. The pastoral districts of England range from 46 in Central Wales to 269 in Somersetshire. The agricultural districts are, of course, higher than the pastoral, and Suffolk with 244 may be taken as an average. In the mining and manufacturing areas the density becomes very great, Lancashire having over

2,000, and Lanark 1,524. A striking contrast between the density of an industrial and that of a pastoral county is to be found in the fact that Glamorganshire with its coal-fields has a density per square mile of 1,060, while the sheep-grazing county of Westmorland, which is about the same size, has only 82.

In pre-Victorian days, when agriculture and textiles woven by water-power or in hand-looms were the chief occupation of our people, the densest population in England lay between Norfolk and the Bristol Channel. The discovery of steam motive-power led to the growth of the big towns on those spots where fuel was plentiful, *i.e.* on the coal-fields.* This led to the centralisation of previously scattered industries, a movement that is still spreading even to such scattered industries as dairy-farming. The unfortunate result of this overcrowding of the industrial centres, or worse still, the amalgamation of overcrowded centres, has led not only to the depopulation of the rural districts in our lands, and the consequent enforced decay of agricultural production, but also to the production of the pale anæmic factory-worker, and the threatened decadence and degeneration of the nation's manhood.

Growth of Towns.—Wherever people, having adopted a settled life, grouped themselves in specially chosen and presumably favourable localities, towns ultimately grew. In Europe and North America especially, the two greatest areas of civilisation, commerce lies at the root of the growth of most towns, and in Europe, for centuries a theatre of various wars, the further element of defence was superadded. For towns that came thus into existence previous to the time of the English Tudors there were three predominating circumstances that governed the choice of site. Firstly, there was the circumstance of sea-trade, which led to the origin of towns on the coasts of countries where there were good natural harbours or convenient access to other trading centres. Such a circumstance as this led to the founding of ports like Alexandria, Marseilles, New York, and Rio de Janeiro. Then there was the circumstance of an easily defended position, either on a commanding hill like Edinburgh, or in the bend of a river like Durham, or at the opening to a large plain like Dublin, and so forth. Ease of defence likewise gave origin to cities like Athens, Quebec, and Prague. Lastly, there was the circumstance of inland trade, which caused towns to spring up at all points where two or more land or water trade routes converged. Such a circumstance accounts for the origin of towns like Cologne, Lyons, Budapest, Allahabad, and Rome.

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* Before the industrial revolution iron was smelted by charcoal, and certain forest areas were industrial centres. The railings round St. Paul's Cathedral were smelted with charcoal on the Weald in Sussex, as also were the guns used by Nelson at Trafalgar.

Variations of these three chief factors, together with subsidiary circumstances, will account for most towns that have come into existence during the last three hundred years. At the mouths of most navigable rivers there has also sprung up a port either at the lowest possible bridging point, or at the highest point of ocean navigation, or again at the highest point of river navigation. Such towns are Bordeaux, New Orleans, Hankow, Calcutta, London, and Rome. There is usually in the district behind a port some definite product, industrial or agricultural, which necessitates an outlet, such as Cardiff, the outlet for Welsh coal, Hull, the outlet for Yorkshire woollens, or Rangoon which exports Burmese rice and teak. If there is no such *raison d'être* for the existence of a port, the navigable river, the sheltered estuary, or the good natural harbour can nevertheless be utilised as a packet-station or as a naval station, as is the case with most of the ports along the south coast of England. A gap through a ridge of hills, or between highlands and the sea, is usually the site for a town; for the ridge being easy to cross at such a place would bring inland trade routes converging to the gap. Leeds, Canterbury, Maidstone, Lincoln, Carlisle, Dumbarton, Perth, Stirling, Berwick, Toulouse, and Narbonne are well-known gap-towns. But the easy crossing of a ridge, besides giving easy passage to trade routes, also gave easy passage to an invading enemy. Hence many gap-towns were originally military towns built for protective purposes. These may remain purely military stations like Peshawar, or may later become important commercial centres like Turin or Milan. The commonest cause for the birth of a town, however, is the intersection of main land routes—the confluence of a tributary with a main stream is a similar convergence of water routes—such as Bokhara at the intersection of caravan routes. The best known of such trade-route towns are Glasgow, Breslau, Vienna, Orleans, Chester, Coblentz, Lyons, Kazan, Duluth, St. Louis, Khartoum, and Allahabad. Sometimes a town remains to mark the point in the course of a river where formerly there was an easy crossing, either by ford or bridge, like Cambridge, Oxford, Hereford, Bridgewater, and Innsbruck. Many modern towns owe their origin to some natural product being found in a particular locality, such as salt at Northwich and Nantwich, flints at Brandon (Suffolk), or quicksilver at Almaden (Spain). There are cases, however, where, although the natural product gives out, the town remains and carries on an old industry with imported material, like Keswick, which now for its black-lead pencils imports the graphite from Ceylon and the cedar from Florida. The presence of coal and iron led to the founding of the groups of towns in South Lancashire, the Potteries, and the Black Country. Other causes for the growth of modern towns are the presence of good water-power like Minneapolis, the necessity for an outport for the largest ocean-going vessels like Barry Dock and Avonmouth, the presence of medicinal waters as in the case of Matlock, Buxton, and Harrogate (Bath is not a modern watering-place), or the growth of the tourist industry as at Ambleside and Hammerfest. The presence of railway junctions may tend to develop the size and importance of a town, as in the case of Carlisle, St. Louis, Chicago, Delhi, Agra, and Cawnpore, the last three of which the railway rescued from decay. Finally religion is a strongly attractive force in swelling a town's population. Examples of "pilgrim" towns are Rome, Cologne, Canterbury (where pilgrims came to worship at the shrine of Thomas à Becket), and in the East particularly we have many notable examples in Jerusalem, Mecca, Allahabad, Amritsar, Madura, and Benares, the wealth of the last-named depending almost entirely on the constant influx of rich Hindu pilgrims from every part of India.

EXERCISES

1. Why is the population in Ireland scattered and in Scotland concentrated?
2. Why is Denmark a purely pastoral country?
3. What parts of Russia are to-day inhabited by (*a*) hunters, (*b*) nomads, (*c*) farmers?
4. In what parts of the world can we find the following tribes or races, or traces of their former existence:

Maories, Kaffirs, Hottentots, Aztecs, Malays, Eskimo? (Camb. Jun. Loc.)

5. What parts of Asia are inhabited by nomadic peoples? In what way do these nomadic peoples make a living? In what kinds of lands are these nomadic peoples found? (Oxf. Sen. Loc.)
6. What parts of the world are inhabited by negroes? Say in each case whether the negro was originally a native of, or has been brought to, the regions you name. Describe the appearance of a typical negro. (Oxf. and Camb. Lower Cert.)
7. Write an essay on the influence of climate and geographical environment on the national character of Negroes, Danes, and Spaniards.
8. What are the great divisions of the peoples of Europe according to race and language? Name the countries which these races severally inhabit. In what countries is the population most dense. (Civil Service.)
9. Enumerate the chief divisions of the human race, mentioning their peculiar physical characteristics, and stating the portions of the world inhabited by them.
10. Give an account of the distribution in Europe of the peoples speaking Teutonic, Keltic, Greek-Latin, and Sclavonic languages. (Oxf. and Camb. Sch. Cert.)
11. Give a brief account of the different races (other than Anglo-Saxon) which are to be found in the European and Asiatic parts of the British Empire. State where each is to be found. (Oxf. and Camb Sch. Cert.)
12. Mankind is commonly divided into four races. Give the names of these races, and describe shortly some of the distinguishing characteristics of each.

State the principal regions where each is found. (Oxf. Sen. Loc.)

13. Write an essay on the following subject:

    Environment versus Race in the interpretation of national characteristics. (Civil Service.)

14. What do you know of the native races of Australia and New Zealand? (Camb. Jun. Loc.)

15. Give an example of a region which supports a dense settled population engaged in agriculture. Explain the conditions which make this possible in the region you select. Name the most important crops cultivated. (Oxf. Sen. Loc.)

16. Discuss the more important geographical causes which lead to the foundation and growth of towns. Illustrate your answer by reference to towns in Great Britain and North America. (Civil Service.)

17. Describe and account for the distribution of population in India or Australia. (Oxf. and Camb. Lower Cert.)

18. Compare the importance of ports situated (*a*) on a fiord, (*b*) at the mouth of an estuary, (*c*) at the head of an estuary, (*d*) where an island lies off a sandy coast. Give illustrations taken from the British Empire of the importance of each of these situations for a port. (Oxf. and Camb. Sch. Cert.)

19. What parts of Europe are most densely populated? What parts have fewest inhabitants? Give explanations. (Oxf. and Camb. Lower Cert.)

20. Explain as fully as you can why the lowland regions of the temperate zone are the most suitable for habitation by civilised man. Give examples illustrating your answer. (Oxf. Jun. Loc.)

21. Give an example of a district in which there are many fairly large towns situated close together. Mention

some of the geographical causes which have brought this about in the district you mention. (Oxf. Jun. Loc.)

22. Towns frequently arise (*a*) at river mouths, (*b*) at the confluence of two rivers, (*c*) at a point where two trade routes cross, (*d*) at one end of a pass, (*e*) in a district rich in mineral wealth. Give one example of each of the foregoing. Describe carefully the position of each town you select and explain briefly the particular reasons which have led to its growth. (Oxf. Sen. Loc.)
23. Give full geographical or other reasons for the foundation and development of the following towns—Lyons, New Orleans, Carlisle, Allahabad, Milan.
24. Discuss, with examples, the effects of mountains on the distribution of population. (Oxf. Sen. Loc.)
25. Discuss the effect of the introduction of improved methods of land transport (*e.g.* railways) upon the geographical distribution of towns. (Civil Service.)
26. The monsoon region of Asia is estimated to contain seven-eighths of the inhabitants of the continent, although it includes only about one-quarter of the area. What are the conditions which favour the large population ? Mention any parts of the monsoon region not thickly populated, and give reasons why they are not. (Oxf. Jun. Loc.)
27. Describe the geographical conditions which make the keeping of flocks and herds the chief occupation of the inhabitants of certain parts of the world. Give examples of such regions. (Oxf. Sen. Loc.)
28. In what parts of the world do we still find true nomadic tribes ? Show how their manner of life is controlled by their environment. (Lond. Univ. Matric.)

PART V

MAPS AND MAP-MAKING

CHAPTER XXXIV

The Mapping of Areas

In the plotting and making of maps from actual surveys there are at least three well-known instruments that may be employed, viz. (1) the Plane-table; (2) the Prismatic Compass; (3) the Theodolite. Each of these has its own special purpose. For mapping small areas the plane-table is best suited, and it has the advantage of enabling one to measure distances, fix the relative positions of all objects, and at the same time draw the map as the actual area is being surveyed. When only an approximate survey is desired, the prismatic compass is generally employed. For military purposes this instrument is of inestimable value, although magnetic attractions frequently endanger the accuracy of the observations. The rapidity with which observations may be taken and noted in the field-book allows more ground to be covered in a short time than would be the case with a plane-table survey; but it must be remembered that the map has to be drawn afterwards from the note-book. Hence it is difficult to verify or correct any error that may have been made during the actual survey without once more going over the ground. The theodolite is, however, the most suitable instrument of all to use in surveying work; especially is this the case when a large area is being surveyed. From the nature of its construction the most accurate observations may be secured, and this is of much consequence in dealing with the positions of objects which are a considerable distance from the place of observation, when an error of one degree in an angle may mean an error of half a mile or more on the map. Furthermore, the theodolite permits the observer to take observations of altitude at the same time as he is making the survey, and thus to determine heights at different places on the map from which he may afterwards draw in the contour-lines.

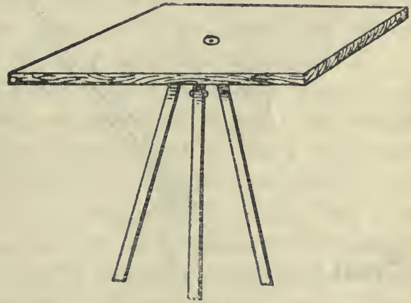
Fig. 118.

The Plane-table.—The plane-table (fig. 118) consists of a rectangular board fitted to a tripod stand by a thumb-screw from underneath. Inset in the board is a spirit-level to assist in levelling the table before taking observations. A compass and a sighting-ruler (which consists of an ordinary ruler, to each end of which is attached a sight) are all that is required to make a survey.

To illustrate the manner in which it is used, let us imagine that the accompanying diagram (fig. 119) represents a plan of a small area to be surveyed. The plane-table is first erected at *A*, then levelled, and a sheet of drawing-paper firmly pinned on it. The compass * is next placed

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* This should be a magnetic needle in a rectangular box, the side of which is parallel to the needle when pointing north.

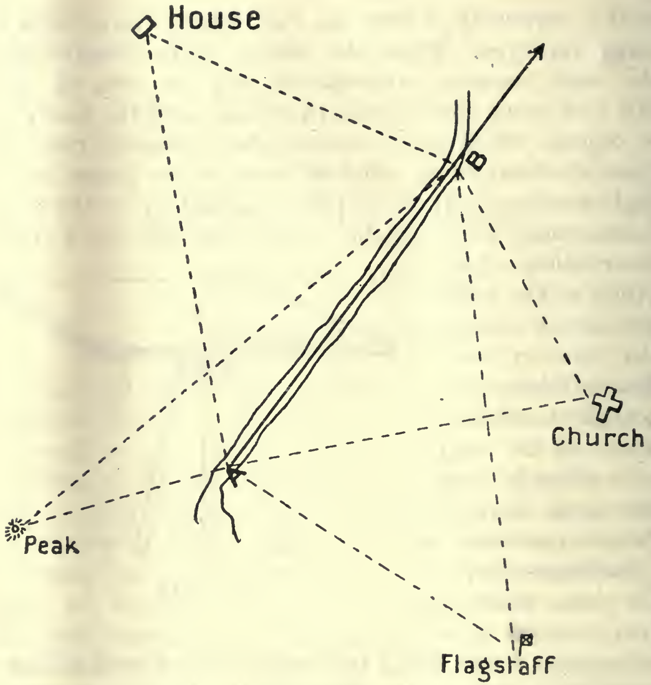

Fig. 119.

on the table and adjusted. A line is then ruled along the edge of the compass-box. This line is parallel to the direction in which the needle is pointing, and therefore gives us the direction of the magnetic north.* The length and breadth of the area to be mapped should now be estimated by the eye, and compared with the dimensions of the paper so that a suitable scale can be chosen. Any scale ranging from $\frac{1}{2}$ inch to 4 inches to the mile will be found to be satisfactory for mapping small areas.

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* An allowance must be made for variation if the true north is required (see p. 43). London has 16° W. var.

A point *A* is now fixed on the paper, and the sighting-ruler is placed on the board so that lines may be drawn from *A* in any direction. The ruler is then rotated till on looking through the sights the peak is seen in a direct line (fig. 119). A line is then drawn along the edge of the ruler in the direction of the peak. The ruler is again rotated till the house is seen, and another line is drawn on the paper in like manner. The directions of the church and flagstaff from *A* are also determined.

A boy is next sent a convenient * distance away to *B*, from which station the objects just sighted are clearly visible. The boy is then sighted from *A* and a line drawn on the paper in his direction. The distance *AB* is measured by the chain and its equivalent marked off from *A* on the paper. The table is now taken down from *A* and removed to *B*. Here it is again set up and levelled. The sighting-ruler is then placed at the point *B* on the paper so that its edge lies along the line *BA*. The board is next rotated till on sighting along the ruler the point *A* comes into a direct line with the sights. When the table is clamped, all the objects previously sighted at the former station are again sighted in turn and lines drawn in their direction. The positions of the objects are represented on the paper where these lines intersect those drawn from *A*.

Other stations may be chosen and prominent objects sighted from them in like manner. When the prominent features of the district are plotted the lesser details may be drawn in on the map by the eye. A complete map of the district will then have been prepared.

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* The distance chosen is known as the *base-line*, and its length depends solely on the area of the district to be mapped and the scale of the map. If the area to be mapped only includes the immediate surroundings of your school, a convenient distance would be two or three chain-lengths. For greater areas a longer distance would, however, have to be chosen.

Fig. 120 is a map of a boys' school and surroundings that has been drawn by means of the plane-table. The prominent features seen from the playground, such as the position of the school buildings, the corners of the school grounds, the church, and the direction of the main streets, were first determined. The less important features were drawn in by judging their relative positions by the eye.

It is suggested that not more than four or five boys should be permitted to work at each table. More than that number only leads to confusion. Before attempting to make a survey on a large scale it is well to commence by making plans of the positions of objects in the school grounds, so as to secure ease in the management of the table.

The Prismatic Compass.—This instrument (fig. 121) is a much more simple instrument than the theodolite, but is of delicate make and requires careful handling. It consists of a compass-card to which is attached a compass-needle. The needle is so fixed that the north mark on the card is directly over the south pole of the needle. This explains why all readings taken by the instrument are *east* of a magnetic north-to-south line. Both the card and needle are enclosed in a circular metal case to which a prism with an eye-piece and a sight-vane (directly opposite the prism) are attached. The sight-vane is so fixed to the metal case that on raising it on its hinge into a vertical position the card is free to rotate within. Its rotation may be at any time prevented by pressing a small button underneath the sight-vane. By means of the prism two things may be seen at the same glance: (*a*) the distant object whose direction is required, and (*b*) the reflected image of the degrees by which that direction diverges from the north on the com-

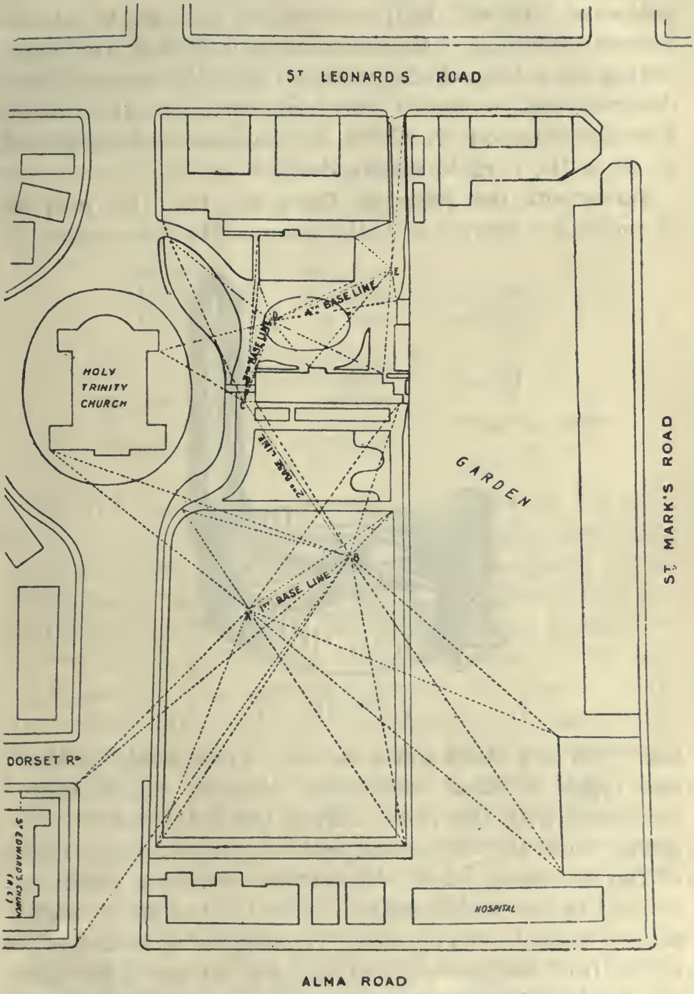

FIG. 120.—Map of School Grounds surveyed by Plane-table.

pass-card. It will be found rather difficult to obtain accurate readings if the instrument is held in the hand during the taking of observations, since the compass-card does not easily come to rest. Hence it is well to carry a stake or tripod on which the compass may be placed to allow the card to steady itself.

Survey with the Prismatic Compass.—For the purpose of making a survey with the compass it is necessary to take with us a chain and a surveyor's note-book, in which each page is ruled into three columns. All distances measured with the chain during the actual survey, together with the deviations east of the magnetic north of the line along which observations are being made, are entered in the *middle* column from the bottom upwards, as seen in the table opposite. The angle of deviation of an object from the north-to-south line is entered in the *right-hand* column opposite the figure in the middle column, that shows the distance of the point of observation

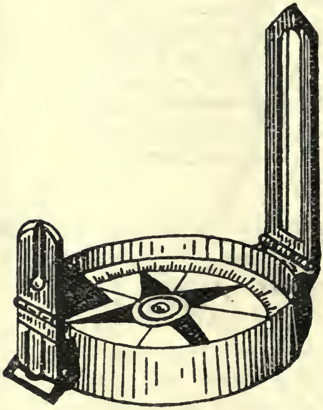

Fig. 121.

from the starting-point—that is, if the object lies to the *right* of the direction in which the survey is being made. On the contrary, if the object sighted is situated on the *left-hand* side, then the angle of divergence is entered in the *left-hand* column. This will be best explained and understood from the following example :

	D 76 yards	
River 5°	54 yards	
	75°	
River 33°	*C* 126 yards	
Hill 300°	86 yards	Grove 95°
Hill 340°	54 yards	Grove 80°
	43°	
	B 115 yards	
	90 yards	Chapel 184°
Mansion 285°	70 yards	
	35 yards	Cottage 25 yards
Mansion 42°	20 yards	
	A 65°	Chapel 120°

Fig. 122 represents a map of a district that has been surveyed with the prismatic compass. The data from which the map was drawn are seen in the table above, which was compiled as observations were made along the road from *A* to *D*. The point *A* was chosen as the first station, and *B*, at the bend of the road, was sighted with the compass. The angle of deviation, 65° east of north, was written down in the middle column of the note-book. As the chapel on the right seemed to be an important landmark, its bearing to the east of north (120°) was found and entered in the right-hand column opposite *A*, the point of observation. Twenty yards along the road, a mansion came into view on the left. This distance from *A* was entered in the middle column, the angle of divergence and name of object (mansion 42°) were entered in the left-hand column, since it appeared on our left. Thirty-five yards from *A*, a cottage was seen on the right, and its distance from the road-side was measured and found to

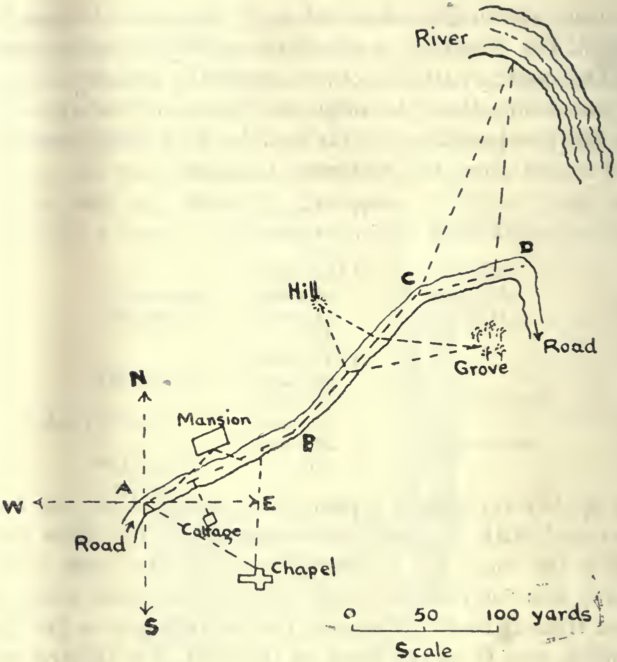

FIG. 122.

be 25 yards. These figures were noted down as shown in the table. Seventy yards from *A* the mansion was again sighted, and the angle (285° east of north) entered in the left-hand column. The chapel was once more sighted 90 yards from *A*, and the angle 184° east of north entered. When *B* was reached, the total distance of 115 yards from *A* was entered in the middle column. And so on, to the end of the table.

The construction of the map from the data in the table is an easy matter. First choose a convenient scale (say 1 inch to 100 yards) and fix a point on the paper to mark the station *A*. Then draw a magnetic north-to-south line passing through *A*. To the east of this line make an angle of 65°, since the bearing of *B* was found to be that angle, and mark off a part to represent a distance of 115 yards according to the scale. The end of this line gives the position of *B*. At their respective distances along *AB* the angles of divergence obtained during the actual survey are made to the right or left as the case may be, and the positions of the chapel and mansion are thus determined. Since the cottage was not sighted but its distance from the road measured, its position is located by erecting a perpendicular to *AB* at a point 35 yards distant from *A* and marking off a part equal to 25 yards in accordance with the scale. In like manner the positions of all other objects may be plotted until the map is complete.

Surveying with the Theodolite.—Before making a survey of a large or small area with the theodolite (see fig. 32), a clear idea should be obtained of the method by which the bearings of different objects are to be found. In all cases a *base-line** is first chosen. Then the direction of the magnetic north-to-south line is definitely fixed by the instrument. When this has been satisfactorily determined, the bearing of any object is *always* reckoned by the number of degrees it lies west of south. This is known as the **azimuth** of the object. Now, if the azimuth of two objects is known, the angle subtended at the place of observation is equal to the difference of the azimuths. Some practice is

* A base-line is a line measured out along the ground, from the ends of which the bearing of each object is determined. In the case of finding the height of an object, a line is measured out along the ground towards the object and the angles of elevation of the object are determined from its extremities. This line is so called, because it forms the base of the triangle from which we are enabled to calculate the distance away or the height of the object, and the method of working is termed *surveying by triangulation.*

necessary in finding azimuths before proceeding to map a district, so that it would be well to give a practical example of the method followed. In fig. 123, *A*, *B*, *C*, *D* represent the positions of the four corners of any four-sided area. At the corner *A* the theodolite was set up to determine the azimuth of *B*, *C*, and *D*. When the instrument was levelled and the magnetic needle placed on the pivot in the centre of the sighting-rod, the rod was rotated by moving the brass pillar until the needle coincided with the mark on the rod. At the same time the index on the horizontal was made to point to zero. An observer standing in position and sighting along the rod would clearly be looking in the direction of the magnetic south, and the sighting-hole of the rod would be turned towards the north. This should always be the first position of the theodolite at any station prior to making any observations. To obtain the azimuth of the corner *B*, the rod was rotated to the right until *B* came into view, when the angle registered was read off from the horizontal scale. This angle, being west of south, gave the azimuth of *B*. The rod was then rotated until the corners *C* and *D* came into view and allowed the angles to be noted. In this way their azimuths were determined. The angles *DAC* and *CAB* were afterwards obtained by finding the difference between the azimuths of *D* and *C*, and those of *C* and *B*.

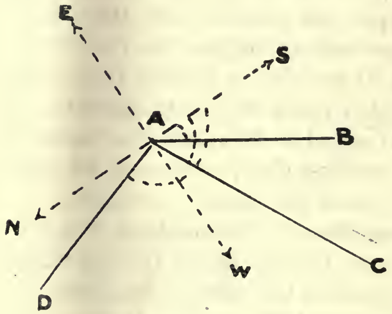

FIG. 123.

In surveying a large district with the theodolite the method followed is very much like that adopted with the plane-table. A base-line is first chosen and measured. Great care should be taken in the measuring, as a slight error will lead to serious inaccuracies in the subsequent plotting of the map. To prevent this, it is well to measure the line at least three times. At one end of the base-line erect the theodolite, level it and set the index to zero, and at the same time see that the sighting-rod is directed towards the other end of the base. Then clamp the instrument and determine the divergence of the base-line from a north-to-south line by placing the compass-needle on the sighting-rod and rotating the rod until the needle comes to rest. Now sight several prominent features or landmarks, and enter in your note-book the azimuth of each. Move the instrument to the other end of the base-line and adjust it once more. Again sight the objects that were previously observed from the first station and note down their azimuths in your book. Having made these observations, you are in a position to make a survey-map of the district as follows: On a sheet of drawing-paper draw a straight line to represent the actual distance of the base-line you have measured. This may be done by drawing the line to scale. At each end of this line draw a north-to-south line in accordance with the divergence of the base-line as actually determined. Then with your protractor mark off at each end of the base-line the azimuth of each object, as taken from your note-book, in the order in which it was sighted. The position of each object is obtained by noting the point at which each pair of lines drawn from the ends of the base-line in the direction of the same object intersect. By choosing several stations, a map of a fairly large area may be constructed, new base-lines being chosen as the district is covered. In practice, however, it is generally sufficient to measure one base-line, provided that care has been taken to obtain the azimuths of all objects with a fair degree of accuracy. In this case the theodolite may be removed from the second station of the base-line to any one of the objects thus sighted, this object being used as a third station for making observations, and so on. Now, our second base-line is clearly the distance of the object from that end of the base-line which was chosen as our second station. This distance may be readily calculated from our survey-map, since it is obviously one side of the triangle drawn in determining the position of the object from the first base-line. By thus employing the sides of the triangles drawn as new base-lines, we may save ourselves a considerable amount of time in making the actual survey.

Calculation of Areas.—When engaged in mapping districts with the plane-table, prismatic compass, or theodolite, it may frequently happen that one is required to calculate the areas of certain peculiarly curved figures.* Grass plots, for example, are often either circular, elliptical, or parabolic, and we should, therefore, have a knowledge of the formulæ by which the areas of such figures are calculated.

The area of a circle $= \pi r^2$ (where π is a constant value and r is the radius of the circle)

$= 3{\cdot}14159$ or $\frac{22}{7}r^2$ (approximately).

The circumference of a circle $= 2\pi r$.

The area of an ellipse $= {\cdot}7854 \times D \times d$, where D represents the longer diameter or major axis, sometimes called the *conjugate*, and d the shorter or minor axis, sometimes known as the *transverse* diameter.

The length of the curve enclosing the ellipse $=$

$$\tfrac{1}{2}(D + d) \times 3{\cdot}14159 \text{ (approximately).}$$

---

* Definitions and properties of curvilinear figures may be found in any text-book on geometry.

The area of a parabola $= \frac{2bh}{3}$; where b represents its base and h its altitude.

The length of the curve enclosing the parabola $=$

$$2\sqrt{b^2 + \tfrac{4}{3}h^2} \quad \text{(approximately).}$$

The area of a hyperbola may be found approximately by Simpson's Rule. A number of ordinates are drawn at equal intervals from the curve to the straight base-line of the hyperbola. Their lengths having been measured, the area may be calculated by the rule: "To the sum of the first and last ordinates, add twice the sum of all the other odd ordinates, and four times the sum of all the other even ordinates; multiply this result by one-third of the common distance between two adjacent ordinates." This rule may be frequently applied when we are dealing with offsets or ordinates drawn from a base-line to some curved line such as a fence or river. For example:

A field is bounded on one side by a straight fence, and the opposite side follows the curved course of a river. Ordinates are drawn from the curve to the opposite fence at a common distance of 6 feet apart, and are 9 in all, measuring respectively 40, 35, 41, 45, 44, 48, 47, 43, and 49 yards.

To find the area of the field:

$$\begin{array}{rrrr}
40 & 41 & 35 & 89 \\
\underline{49} & 44 & 45 & 264 \\
89 & \underline{47} & 48 & \underline{684} \\
 & 132 & \underline{43} & 1037 \\
 & \underline{2} & 171 & \underline{2} \\
 & 264 & \underline{4} & 3\,\underline{\big|\,2074} \\
 & & 684 &
\end{array}$$

$691\frac{1}{3}$ square yards.

The common distance = 2 yards.

Exercises

1. Use your cyclometer and prismatic compass to make a plan of a district near your school.
2. Draw a plan, scale 1 inch to 100 feet, from the following table :

	C 270 yards	
Wood 65°	264 yards	
	220 yards	Hill 310°
Wood 112°	115 yards	
	20 yards	Hill 224°
	160°	
	B 305 yards	
Church 324°	224 yards	
	145 yards	Cottage 22 yards
Church 15°	87 yards	
	A 42°	

3. Plot the roads, house, and church from the following notes:

	15		0	
		D 118		
	0		15	= Road to "X" 19°
Church 251°	0	74		
		35		
	15	*C* 315°	0	
		132		
	0	107	12	House 40 ⊥
		40		
	15	*B* 28°	0	
		177		
	0	130	15	
Church 5°		30		
	15	*A* 77°	0	

The curves represent bends in the road. At *B* 107 the road is only 12 yards wide, and the house is at right angles to the transverse line. Everywhere else the road is 15 yards wide.

At *A* 30 take first observation of church.

A 130 bend of road is at maximum 0/15. 177 is length from *A* to *B*.

At *B* 40 bend of road is at maximum 0/12.

B 107 take measurement to house. 132 is length from *B* to *C*.

4. Mention the essential parts of a plane-table, and the use of each. Describe how you would, by its means, make a map of the hall in which you are seated. (Birm. Univ. Matric.)

5. An elliptical lawn is surrounded by a gravel path 4 feet 6 inches wide. The transverse and conjugate diameters of the lawn are 18 feet and 13 feet respectively.

   Find the area of the lawn and also of the gravel path. Calculate the total distance round the lawn.

6. A lake is roughly elliptical. A straight line drawn from end to end measures 45 yards, and ordinates drawn from side to side at a common distance of 5 yards are determined by the theodolite to be 6, 12, 18, 19, 22, 17, 15, and 7 yards respectively. Find the area of the lake.

7. Measure out a piece of cord 100 feet long. Fasten it to two vertical short posts placed 80 feet apart. Pull the cord out tightly, and with a stick trace on the ground the figure obtained by walking round outside the poles, so far as the cord will allow. What is the figure thus traced? Find its area.

8. If you started in open country in Africa from a station the latitude and longitude of which were known, and took a chronometer and either a plane-table or a prismatic compass, how would you make a small-scale route-map and how would you from time to time check your position by observations of latitude and longitude? (Oxf. and Camb. Higher Cert.)

9. An exploring party makes a rough survey of a region passed through. Describe generally how the survey may be carried out. (Oxf. and Camb. Sch. Cert.)

CHAPTER XXXV

Heights and Distances

To construct a complete map of any region which will show not only the relative positions of different objects, but also the elevations and depressions of the surface mapped, we must be able to calculate accurately heights and distances. In actual survey work there are many kinds of apparatus which may be used for this purpose. Of these the most suitable are the **theodolite** and **sextant.** While the sextant is held in the hand, like the hand camera, the theodolite can only be used when fixed on a tripod and carefully adjusted, like a stand camera. Latterly many simplified forms of these instruments have been designed for schools, with which fairly accurate results may be obtained. Because of the extreme usefulness of the theodolite in determining heights and distances, in levelling, and in astronomical work, every student should be acquainted with the methods of using it. In the methods here described for the determination of heights and distances, the theodolite to which reference is made is that represented on page 98.

The Theodolite and Heights.—If the object, the height of which you wish to find, is easily accessible, the readiest method of determining its height is to set the rod *D* (fig. 32) at an angle of 45°. Then move the theodolite backwards or forwards in line with the object until you see the top of the object through the two pin-hole sights that are attached to the ends of the rod. Measure the distance between the theodolite and the object, and add to this the height of the sighting-rod above the ground. The result thus obtained gives you the height of the object.

If, however, the object is inaccessible, one of two other methods may be employed. In each case it will be necessary to measure out a line of known length along the ground, called a base-line, from the extremities of which observations of the object should be made. If it is possible, choose the base-line on fairly level ground and in the direction of the object, and proceed according to the method described in the next paragraph. Where this is found to be impossible, the base-line should be drawn in a line parallel to the base of the object like that shown in fig. 126.

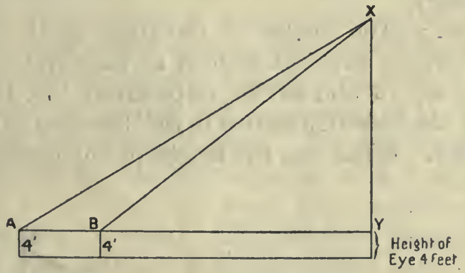

FIG. 124.

Measurement of a Height (1).—Suppose we want to calculate the vertical height of a hill XY (fig. 124). First of all choose what seems to be a fairly level piece of ground from which the top of the hill is clearly visible and measure out a base-line AB.* Set up the theodolite at A and sight the top of the hill along the sighting-rod. Read off from the vertical scale the angle of elevation thus obtained. This angle is represented on the diagram by the angle *XAY*. Move the instrument to *B* and again level it. Here in like manner determine the angle of elevation of the top of the hill. This angle is represented on the figure by the angle *XBY*. The angles of elevation having been thus obtained, the height of *X* may be found by a figure drawn to scale, or, more accurately, by trigonometry.

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* The length of the base-line depends upon the distance you are away from the object. The longer your base-line the more accurate will be your calculations. If you are far away from the object, the base-line must be of considerable length; if quite near, the base-line need only be a couple of chains length.

Example: The angles of elevation of the top of a church tower *A* were determined at each end of a base-line to be 29° 12′ and 36° 30′ respectively (fig. 125). The length of the base-line drawn in the direction of the tower was 66 feet. What was the height of the tower?

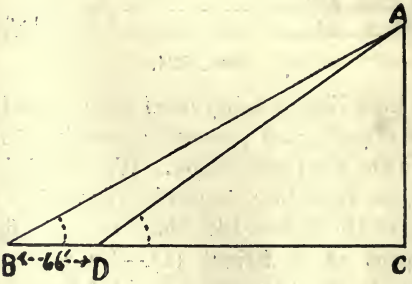

FIG. 125.

$$\text{Cot } 36^\circ\ 30' = \frac{DC}{AC}$$

$$(a)\ \therefore DC = AC \cot 36^\circ\ 30'$$

$$\text{Cot } 29^\circ\ 12' = \frac{BC}{AC}$$

$$
\begin{aligned}
(b)\quad \therefore\ BC &= AC \cot 29^\circ\ 12' \\
BD &= BC - DC \\
\therefore\ 66 &= AC\,(\cot 29^\circ\ 12' - \cot 36^\circ\ 30') \\
\therefore\ 66 &= AC\ (1{\cdot}7893 - 1{\cdot}3514) \\
\therefore\ AC &= 66 \div {\cdot}4379 \\
\therefore\ AC &= 150{\cdot}7 \text{ feet.}
\end{aligned}
$$

Height of theodolite above the ground = 4·83 feet.

∴ Total height of tower = 155·53 feet.

Measurement of a Height (2).—By this method the base-line *AB* (fig. 126) is measured in a line parallel to the base of the object, and the theodolite is first set up at *A*. Here a pole, erected at the other end *B* of the base-line, is sighted along the rod, and the reading on the horizontal scale of the instrument is taken. The sighting-rod is then turned round by rotating the pillar until it points in the direction of *D*, and the angle then registered on the horizontal scale is noted. The difference between the two readings thus obtained is the *horizontal* angle p. While the theodolite remains in this position, the point *C* is sighted and the angle of elevation q of the object is thus

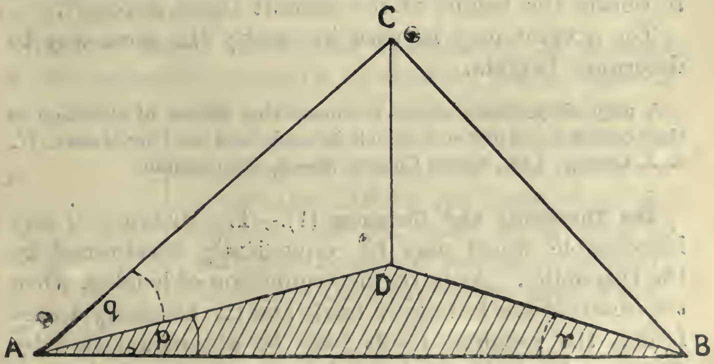

Fig. 126.

determined from the vertical scale. The theodolite is then removed to B, at which station A and D are sighted, the readings being taken on the horizontal scale. The difference of these readings gives the *horizontal* angle r.

$$\text{Tan } q = \frac{CD}{AD}$$

$$\therefore CD = AD \tan q$$

$$\frac{AD}{\text{Sin } r} = \frac{AB}{\sin 180^\circ - (p + r)} = \frac{AB}{\sin (p + r)}$$

$$\therefore AD = \frac{AB \sin r}{\sin (p + r)}$$

$$\therefore CD = \frac{AB \sin r \tan q}{\sin (p + r)}$$

By substituting in this equation the values of the angles determined and the length of AB as measured, the height of the object above the eye may be obtained. To arrive at the total height of CD it will be necessary to add to this the height of the sighting-rod above the ground. If we now know the height of any of our stations above sea-level, the height of any hill or object determined by either of these methods should be added to it in order to obtain the height of the summit above sea-level.

The sextant may be used in exactly the same way to determine heights.

A very simple instrument for measuring angles of elevation is that called the Altimeter, which is made and sold by Messrs. W. & J. George, Ltd., Great Charles Street, Birmingham.

The Theodolite and Distances (1).—The distance of any inaccessible object may be conveniently determined by the theodolite. As in the determination of heights, when the observations have been made and the necessary angles found, the required result may be obtained either by drawing to scale or by trigonometrical calculations.

Suppose we wish to measure the distance of a tower *T* (fig. 127) which is visible from two points *A* and *B*. Set up the theodolite at *A* and, having levelled and adjusted the instrument, direct the sighting-rod towards *T*. Take the reading on the horizontal scale. Rotate the sighting-rod until it is seen to point in the direction of *B* and again take the reading on the horizontal scale. The difference between the two readings gives the angle *TAB*. Next move the theodolite to *B* and in like manner determine the angle *TBA*. Measure the length of *AB* with the chain. A similar figure may now be drawn to scale from these data, and the actual distance of *T* from *AB* may be obtained by letting fall a perpendicular *TC* on *AB*, and reading off the actual distance this line represents according to the scale chosen.

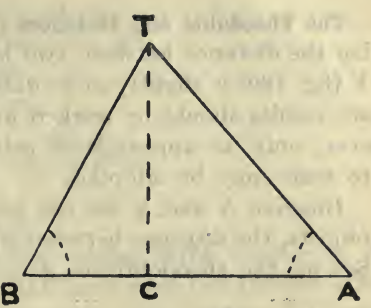

Fig. 127.

Another simple method for ascertaining the distance of an inaccessible object is to sight at *A* the object *T* (fig. 128), and take the reading on the horizontal scale. Next rotate the sighting-rod through 90° and mark out a base-line *AB* in the direction of *W*. Remove the theodolite to *B* and, by taking the horizontal readings of *A* and *T*, determine the value of the angle *TBA*.

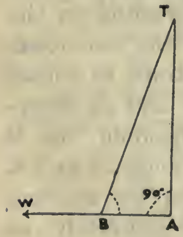

Fig. 128.

$$\text{Tan } TBA = \frac{AT}{AB}$$

$$\therefore\ AT = AB \times \tan\ TBA.$$

The Theodolite and Distances (2).—The method of finding the distance between two inaccessible objects X and Y (fig. 129) is slightly more difficult, and to ensure accurate results should be worked by trigonometry. If, however, only an approximate estimate is desired, drawing to scale may be adopted.

Imagine X and Y are the positions of two inaccessible objects, the distance between which it is required to find. Set up the theodolite at A and measure out a suitable base-line AB. Sight the point B and take the reading on the horizontal scale. Rotate the sighting-rod until it points towards X, and again take the reading on the horizontal scale. The difference between the two readings gives the value of the angle p. Continue to rotate the sighting-rod until Y comes into view and so determine the angle q. Next remove the theodolite to B and in like manner find the value of the angles r and s. The length of XY may then be obtained by drawing a similar figure to scale, but more accurately as follows:

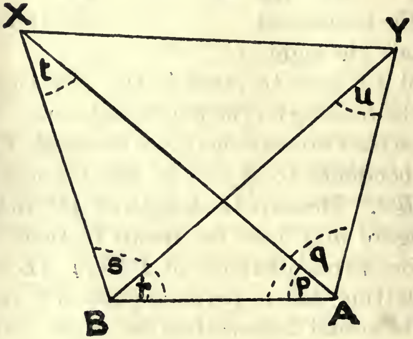

FIG. 129.

$$\text{(i)}\ \frac{BX}{AB} = \frac{\sin p}{\sin t} = \frac{\sin p}{\sin (s+p)}$$

$$\therefore BX = \frac{AB \sin p}{\sin (s+p)}$$

$$\text{(ii)}\ \frac{BY}{AB} = \frac{\sin q}{\sin u} = \frac{\sin q}{\sin (r+q)}$$

$$\therefore BY = \frac{AB \sin q}{\sin (r+q)}$$

In the triangle XBY the angle $XBY = (s - r)$ is known, and the sides BX, BY have been determined from the formulæ (i) and (ii), therefore the distance XY may be found from the relation that exists between the sides and angles of a triangle.

If the theodolite is not available, a simple instrument for measuring horizontal angles called the Circum-Meter may be obtained from Messrs. W. & J. George, Ltd., Great Charles Street, Birmingham.

Exercises

Solve the following examples by drawing to scale:

1. The angles of elevation of a church on a hill, as seen in a direct line from a plain, are found to be 45° and 85°; the distance between the two points of observation is $\frac{3}{4}$ mile. Determine the height of the church above the plain.
2. At a distance of 650 feet from the base of a tower the angle of elevation of the tower is found to be 35°. What is the height of the tower?
3. A factory chimney is observed to have an angle of elevation of 30°. On walking 110 yards towards it the angle is then observed as 45°. What is the height of the chimney?
4. A cliff 80 feet high is found to subtend from a boat an angle of 45°. There is a flagstaff on top of

the cliff which also subtends from the boat an angle of 51°. What is the height of the flagstaff?

Solve the following examples by trigonometry:

5. A church spire 120 feet high subtends an angle of 1·5°. How far distant is the spire?
6. The direction of a lighthouse as seen from a liner makes an angle of 40° with the direction in which the liner is sailing. When the liner has sailed two miles, the angle is found to be 66°. How near the lighthouse will the liner pass?
7. From a milestone the elevation of the top of a hill is 40°, and that of the top of a tower beyond the hill is 54°. The elevation of the tower as seen from the hill is 60°. If the tower be 120 feet high, what is the distance between the milestone and the hill?
8. To a man walking along a road that runs S.E., a certain house is observed to lie due E. When the man has gone 2½ miles he finds the house to lie N.N.E. What is the shortest distance from the house to the road?
9. The mast of a stationary ship which is lying east of the observer has an altitude of 45°. If the observer now walks S.E. of his former position for a distance of 50 yards, he finds its altitude to be 60°. Calculate the height of the mast.
10. The distance between two trees *A* and *B* is 210 feet. From a point of observation *C*, the angle *CAB* is 75°, and the angle *CBA* 60°. What is the distance from *C* to *A*?
11. An aeroplane travelling in a direction parallel with the ground is observed by a person standing at

A to have an elevation of 60°. The observer motors $\frac{1}{2}$ mile along a straight road in the same direction as that in which the aeroplane is travelling and there finds its elevation to be 45°. What is the height of the aeroplane above the road ?

12. A boy with a sextant finds the angle made by an object on the opposite bank of a river and another object on the same bank as he is standing to be 35°. He now walks along the bank till he reaches the second object and finds the angle made by the first object and the direction he has walked to be 60°. If the distance walked be 100 yards, what is the breadth of the river ?

13. *X*, *Y*, and *Z* are three objects *X* is 4 miles distant from *Y* and lies N.W. of it. From *Z*, *X* lies N. 30° E., and *Y*, N. 60° E. Find the distance of *X* and *Y* from *Z*.

14. Calculate the height of your school buildings by the methods described in the chapter, also use the theodolite to determine the distance of some inaccessible object and the distance between any two inaccessible objects.

15. Calculate the area of your playground, by measuring one of its sides and finding the angles at each of its corners with the theodolite or circum-meter.

CHAPTER XXXVI

Contours

Definition of Contours.—A fairly accurate representation of any small portion of the earth's surface can be obtained from a relief model which will reproduce the unevenness of the earth's surface. There are, however, other devices by which the earth's profile may be graphically represented. One of the most important of these is to draw certain lines on a chart or map known as **contour lines.** Every contour line is drawn so as to denote that *all places through which it passes are the same height above a certain fixed level.* The level from which all contour lines are measured is **sea-level.** Because of the varying changes in level of the sea at different periods an average level is taken, and that level is recognised as the *datum* line from which elevations and depressions on the earth's surface are measured. In the British Isles the datum line is the average between high- and low-water mark at Liverpool. We may, therefore, define contour lines as *lines connecting all places having the same elevation above a chosen mean sea-level.* On every contour map the vertical height above sea-level is always marked on the contour line. The horizontal distance between the contour lines, not the slant height, is represented on the map by the interval between the contour lines.

A contour map has something in common with isothermal and isobaric maps (see pp. 146 and 218), since isotherms are drawn through places of equal temperature, and isobars are drawn through places of equal air-pressure. In drawing each of these lines a certain fixed base has been chosen from which measurements are made.

Gradients.—A gradient is the degree of rise in a slope between any two points. We may calculate a gradient from a map if we know the scale of the map and the vertical heights of the two points. The scale to which Ordnance maps are drawn is always given on the map as a fraction, often spoken of as the representative fraction, which is usually written R.F. The ratio which the numerator of the fraction bears to the denominator is the proportion which any distance measured on the map bears to the actual distance measured on the ground. For example, the R.F. on the "Six-Inch" Ordnance Map is $\frac{1}{10560}$. Sometimes the term *stream-line* (that is, the line along which water would flow) is applied to the line of actual slope between the contours on a map. The gradient varies inversely as the stream-line—*i.e.* the shorter the stream-line, the steeper the gradient. Now, suppose that two points A and B on a map are situated at an elevation of 210 feet and 350 feet respectively; their distance apart as measured on the map, *i.e.* horizontal distance, is ½ mile. Then the gradient equals the difference in elevation divided by their distance apart, or to express this as an equation:

$$\text{The gradient} = \frac{VI \text{ (vertical interval)}}{HE \text{ (horizontal or equivalent distance)}}$$

$$= \frac{140}{2640}$$

$$= \frac{1}{19} \text{ (nearly).}$$

This means that for every 19 feet actually measured between A and B there is an average rise of 1 foot.

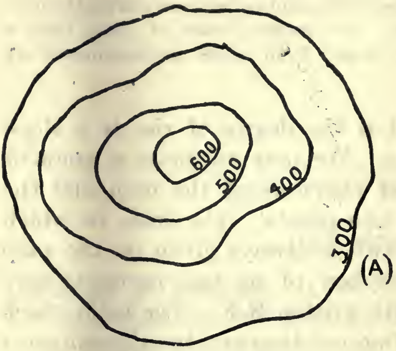

FIG. 130.

Forms of Contours.—There are a few prominent forms of contours to be seen on nearly every Ordnance map, and with them it is well to become familiar. The simplest of these is no doubt the **conical peak** (fig. 130).

The conical peak is represented by a series of irregularly shaped rings. These rings are almost concentric—that is to say, they give the impression of having been drawn successively from the central point of the figure towards the outside. The figures on the contour lines increase from the outside inwards, and reach their maximum elevation on the inside ring. Imagine what would be the effect of reversing the figures, *i.e.* making them increase from the inside outwards. Can you form any idea as to what this type of contour would represent?

A **saddle-back pass** (also called a **col**) is a pass between two hills. It is represented by at least one contour (there may be more) which surrounds the contours representing the two hills. One hill, *C*, is seen to rise to a height of 400 feet, while the

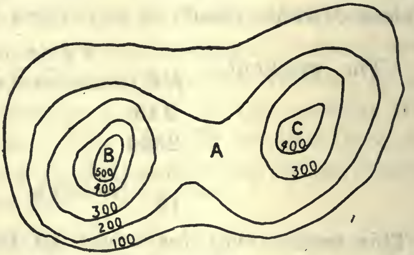

FIG. 131.

other is 100 feet higher. The space between the hills may or may not be level ground, but it is elevated. It has in this instance (fig. 131) an elevation of between 200 and 300 feet, but in no case does it rise higher than 300 feet, so that the pass ends when the 300-foot contour on either peak is reached. The pass is approached on either side by a fairly gradual slope.

If the contour lines marked on the diagram (fig. 131) as 500 and 400 feet at both *B* and *C* were altered to 200 and 100 feet respectively, the form of the contour map would be completely changed. The two hills would thereby be made to appear as depressions or lakes, divided from one another by a narrow ridge of elevated ground. A good impression of the change, which a reversal of the figures would entail, may be obtained, by imagining the hills shown on the diagram to be hollow cones that have now become inverted and embedded in the ground.

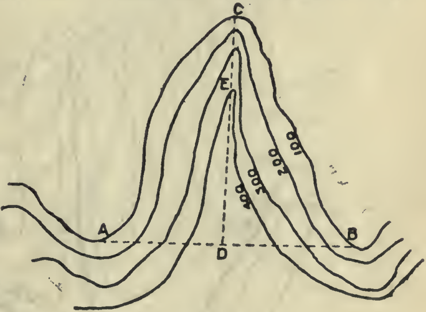

FIG. 132.

Two other typical forms of contours are the **spur** and the **valley** (figs. 132 and 133), which are, at first sight, so much alike, that we must be very careful not to confuse them.

Whenever we observe a number of bends in the contours tapering in the same direction, these indicate either a spur or valley. The difference between them is that in the spur the contour lines run outwards *from* the highest ground; in the valley they run inwards *towards* the highest ground. The spur, therefore, has the *highest* contour lines inside; the valley has the *lowest* contour lines inside. A spur may be, therefore, converted into a valley, or a valley be transformed into a spur by reversing the figures marked on the contour lines.

If we had on our map three or four valleys like that in the diagram (fig. 133), converging one into another, we might expect to find the main stream flowing down the central valley, joined by tributaries coming from each of the convergent valleys. Try to draw a contour map representing this, and insert the river with its tributaries.

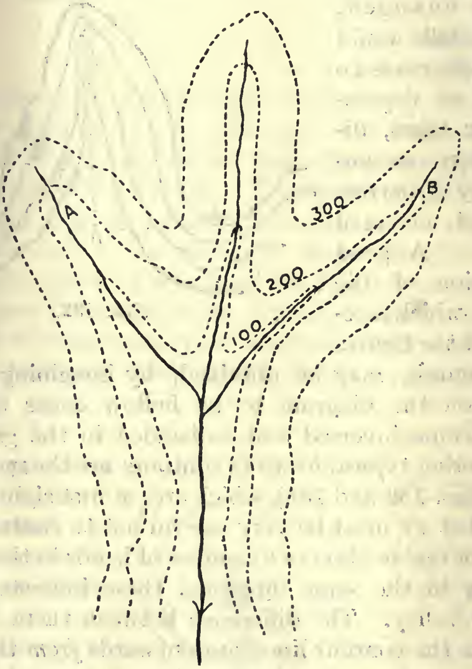

FIG. 133.

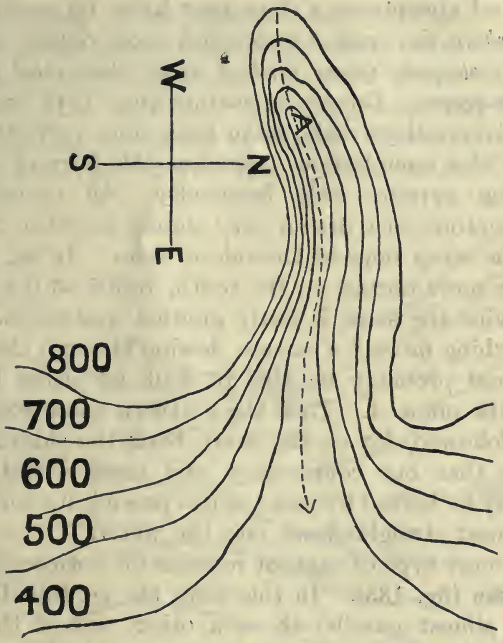

FIG. 134.

The great rule for putting in probable courses of rivers is, *mark the valley-heads.* It should be borne in mind that the rivers flow down the valley-heads where the contours are farthest apart, and that they never flow along straight lines. The wavy line representing the stream should be made thicker as it goes down the valley, and the tributaries should join the main stream at an acute angle, *not* at right angles.* It is an easy matter to determine what degree of abruptness a slope may have, by remembering that *where the contours approach most closely, there the slope is steepest, where farthest apart, there most gentle.*

---

* It should also be borne in mind that rivers do not flow uphill, and hence we must *not* make our rivers flow from (say) a 100-foot contour line across a 200-foot line.

River-gorges.—Gorges or ravines (fig. 134) are simply deep river-valleys with one or both sides very steep. In a map of a mountainous coast-line this form of contour-grouping appears very frequently. All ravines have their contour lines drawn very closely together to represent the steep slope of the side or sides. In fig. 134 the slope is more abrupt on the south, whilst at the head of the ravine the slope is fairly gradual westwards. If we were fishing down * a stream flowing through this gorge, we would probably be able to walk on either bank as far as the point *A*. Then the northern bank would have to be followed, for on the south bank the sides slope so steeply that our course here and there would almost certainly be barred by more or less precipitous rock which ran almost straight down into the water.

One more type of contour remains for notice—the **ridge** or **plateau** (fig. 135). In this form the contour lines are drawn almost parallel to each other, and if the slope towards the plateau from its base is gentle, the contours will be fairly wide apart. It will be seen that there is, in the figure given, a gradual ascent on both sides of the ridge till the 500-foot contour line is reached. After that the ground may be a level plateau, or it may rise over 500 feet and form a ridge; but we know for certain that it does not reach 600 feet—otherwise a 600-foot contour line would appear within the 500-foot.

How to Draw a Contour Map.—" A ridge 400 feet high connects a broad-topped hill whose height is 600 feet, with a conical peak 700 feet high, situated to the south-east of the hill. The hill is indented on its west side by a steep ravine, but its other sides are of gentle declivity. The side of the peak which faces the hill is of more gradual slope than its other sides, which are fairly steep, the south-east side being most so. Express these relations by means of a map with contour lines making intervals of 100 feet vertical height." (Oxf. Jun. Loc.)

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* To fish downstream with fly is generally bad practice.

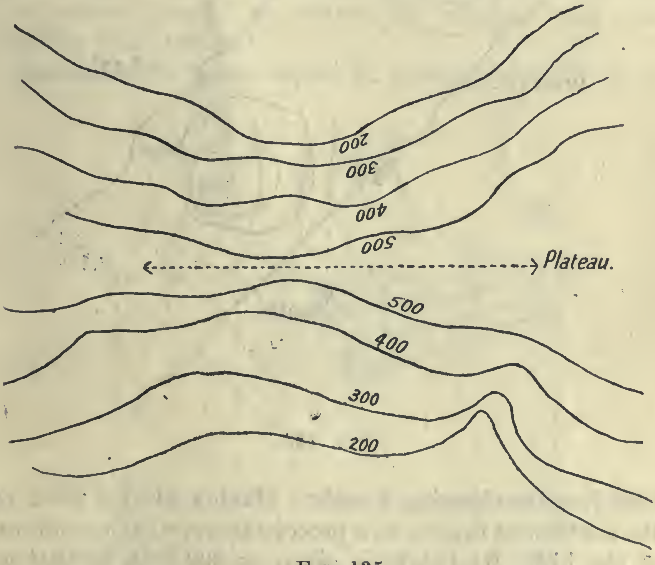

Fig. 135.

The key to the question is found in drawing the direction of the cardinal points on your paper before attempting to insert the contour lines. Let us first draw them as in the diagram (fig. 136). We may now determine the relative positions of the hill and the conical peak by drawing a north-west to south-east line. The distance between the two is not stated, so that we need not trouble

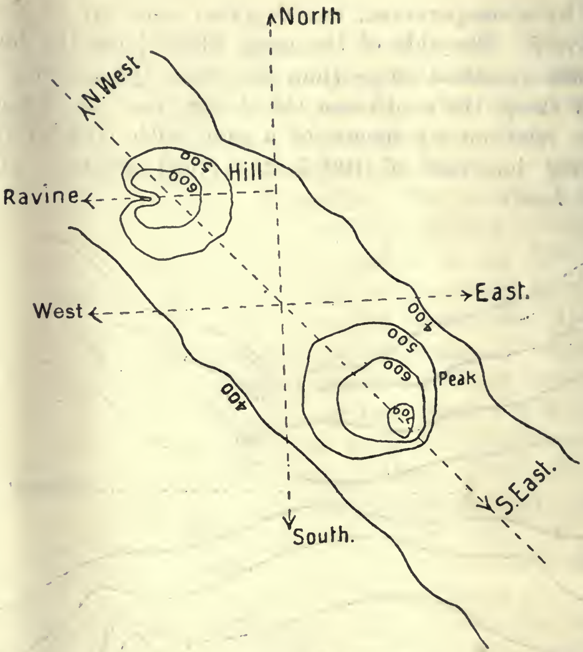

Fig. 136.

ourselves by choosing a scale. Having fixed a point on the north-west line we now proceed to draw in the contours of the hill. Its height is given as 600 feet, so that we shall represent it by drawing two contours only, since the ridge itself is 400 feet high, and contours are at vertical intervals of 100 feet. It is to be indented on its west side by a steep ravine. To represent the abrupt slope of a ravine the two contour lines must be drawn closely together, and in such a way as to penetrate the hill. In order to make the other sides of the hill of gentle declivity, we draw the contours far apart.

The side of the peak facing the hill is of gentle slope, so we draw three contours representing its height at fairly wide intervals apart on that side. As we trace these lines around to show the conical form of the peak, we make them approach each other closely on the south-east side, since we are told that that side is steep.

The ridge may now be shown by drawing two contour lines almost parallel to enclose the hill and peak and marking each 400 feet.

Sections.—The main object in drawing sections is to

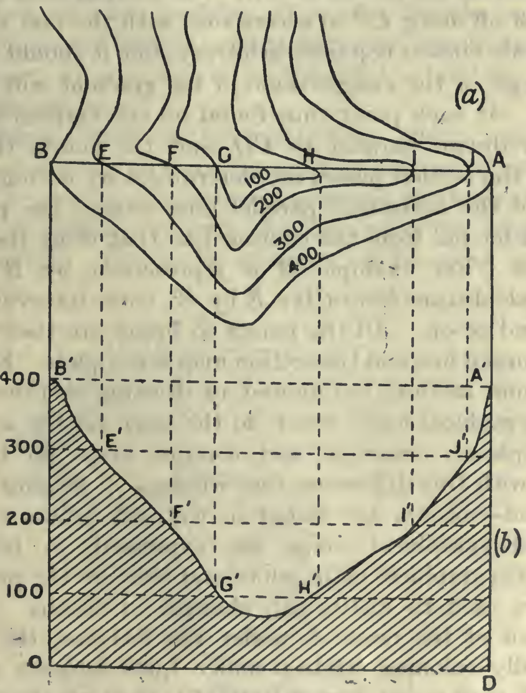

FIG. 137.

give a clear impression of the nature of the profile of the land or sea-floor along any direction. The section is always drawn to an exaggerated vertical scale to mark out clearly the changes of gradient. If the land is fairly level, the vertical scale should be more exaggerated than would be the case if the country were hilly, otherwise the section will not give a good impression of the slope. To draw a section map a horizontal line *CD* is first of all drawn, and perpendiculars from the points at which the section line *AB* (fig. 137) intersects the 400-foot contour are let fall on *CD*. The vertical scale is then marked off along *CB* in accordance with the unit chosen. The scale chosen is purely arbitrary, but it should not be too large, or the exaggeration of the gradient will be too great. At each point thus found on the vertical scale a line is drawn parallel to *CD*, and the points through which the section passes are determined by noting where each of the horizontal parallel lines crosses the perpendicular let fall from the contour line that bears the same number. For example B is represented by B^1, four intervals distant from *CD* ; E by E^1, three intervals from *CD*, and so on. All the points so found are then joined by a curved line and the section map is complete. Exactly the same method is followed in drawing sections from bathygraphical maps which do the same for the sea that orographical, oroscopic, and contour maps do for the land, with this difference, that whereas all heights shown on land-contours are stated in feet, all depths marked on bathygraphical maps are expressed in fathoms. On bathygraphical maps white and blue are the principal colours used to distinguish changes in depths. Where the bed of the ocean is under 100 fathoms, the sea is generally coloured white ; under 1,000 fathoms a light blue is used ; and darker tints of blue mark the deepest parts. Section maps may be also drawn from bathygraphical maps in the following way: Draw a pencil line across the bathygraphical map in question to correspond with the section line that we should find traced on an ordinary contour map for the purpose of drawing a section. Next place a sheet of folded paper along this pencil line and tick off, on the folded edge, all points where there is a change of colouring on the map. The heights of each of these points may be obtained on reference to the colour-index on the map. If we now place the paper on a page of our note-book and draw a straight line along its edge, marking off on this line the positions of all points with their heights corresponding to those on the paper, we can proceed to construct a section map in the ordinary way.

Hachures.—Still another method by which maps are designed in order to show the varying changes of gradient is by a system of shading known as hachuring. The depth of shading entirely depends upon the character of the slope. Where the contours are far apart and the

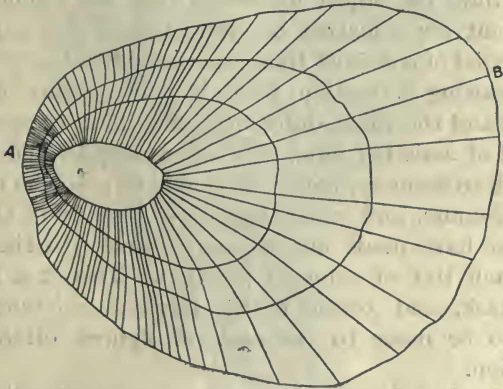

FIG. 138.

slope is gentle, the hachures or short-shading lines are drawn very fine and also far apart from each other. Where the contours are close together and the slope is steep, the hachures are drawn more heavily and close together. The direction of the hachure always lies in the direction which water would take down the slope, so that it corresponds with the stream-line. For this reason hachures are all drawn as nearly as possible at right angles to the contour lines. Peak-summits, plateaux, and ridges are left blank. Hachured maps present us with a general idea of the relative steepness of the slope, as may be seen in fig. 138, but they fail to give us any accurate ideas of the real elevation of a district. Further, much of the topographical value is taken away by the amount of shading which appears on the map.

The Oroscopic Method.—The coloured contour (or orographical) maps and hachured maps have been devised to assist a boy in his attempt to understand what the character of the country may be like that is represented by the map. Many orographical and hachured maps fail to fulfil the object for which they are intended. It is difficult for a learner to gain an accurate impression of the relief of a district from an orographical map without first drawing a section from it. The many different colours and the slight differences of tints in these colours, instead of assisting him, very often mislead and confuse him. Furthermore, before he is able to read the meaning of the colours, and while engaged in a study of the map, he must have made himself conversant with the figures that each tint of colour represents. This is a troublesome task, and, owing to the frequent references that have to be made to the scale of figures, often causes confusion.

The hachured map with its delicate shading lines does

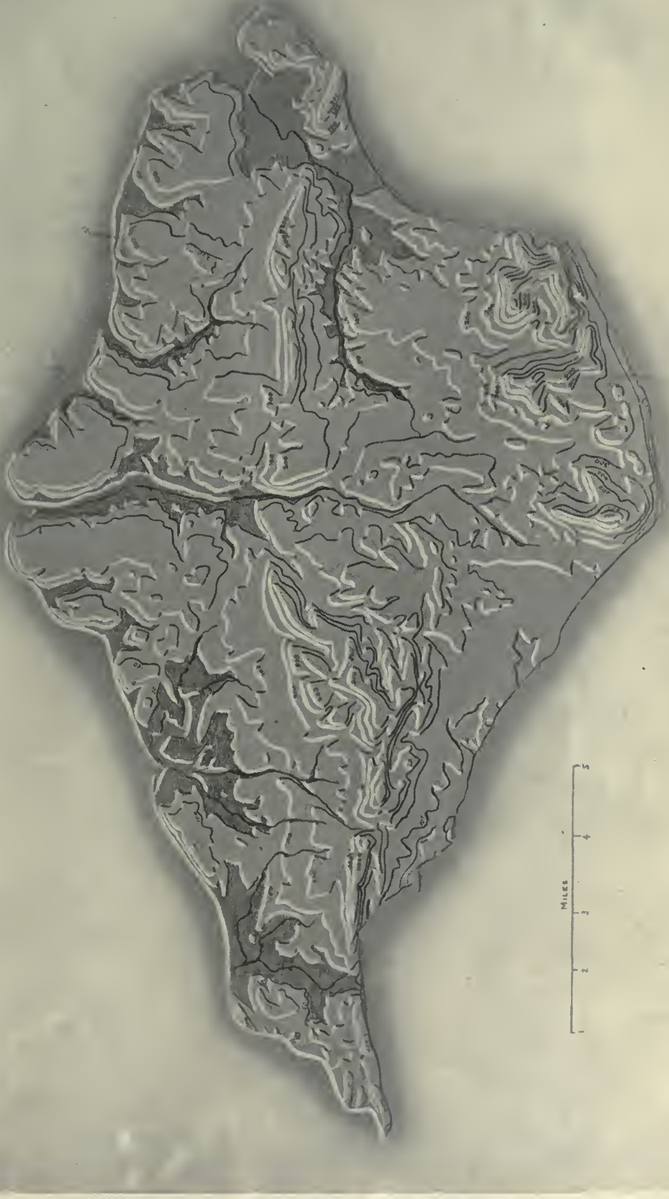

FIG. 139. OROSCOPIC MAP OF THE ISLE OF WIGHT.
Land under 50 feet shaded.

not suffer in the same way. If well hachured, the elevated portions of a region may be seen to stand out prominently, and the valleys may be traced on such a map with some ease. It has, however, one serious defect. Owing to the very fine shading, detail is obscured, and if the contours have been removed, it is difficult to form any but a very rough idea of the actual elevation of any place above sea-level.

The defects outlined in these two classes of maps have to a large extent been overcome by the system pursued in the Oroscopic Series of Maps.* The value of a map drawn on this method will be best seen from a study of the map here shown of the Isle of Wight (fig. 139).

A glance at the map shows that it has none of the defects of the orographical map. It gives one the impression that it consists of layers of cardboard, or some like material, piled one on top of the other. The effect obtained in thus presenting the contour lines is to reproduce nature: to raise up the hills, and to make the valleys seem what they are—real depressions on the surface of the map. The most elevated parts of the island are clearly seen at first sight, while the height of any place on the map may be determined by the fact (1) that land under 50 feet above the sea is shown as shaded, and (2) that the contour lines are drawn at intervals of 100 feet apart.†

The rivers with their tributaries are clearly marked and may be easily discerned as they flow downwards through the valleys towards the sea. In every case, it will be observed, they flow downwards at those points where the contours are farthest apart and the slope most gradual. A remarkable effect of the shading of the map is seen in the river-valleys; where the contour lines bounding the main river-valley are drawn close together, an excellent impression of the abrupt slope on one side is obtained.

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* Published by Messrs. Meiklejohn & Son, 11, Paternoster Square, London.

† Though the highest contour line reaches 700 feet, the actual highest point in the island (which lies in the south-east) attains an elevation of 772 feet.

The Clinometer.—The simplest means of drawing contours is by the use of a clinometer. This instrument (fig. 140) is not difficult to make. Cut out a block of wood of dimensions 6 × 4 × 2 inches, and plane the surface of the block until its faces are perfectly smooth. See that the edge *FE* is parallel to the edge *CD*, and test by placing the block on a level table and laying flat on its top edge a carpenter's level. Now describe on a sheet of paper a semicircle of radius 2½ inches, and divide, with the protractor, the arc into equal intervals of 10 degrees. Mark each of the points where the diameter touches the arc as 90°, and continue to mark off every interval downwards on each side of the arc 10° less than the previous one till you reach 0° at the lowest point of the semicircle. You have now made a graduated scale which should be glued on one face of the block of wood. The diameter of the semicircle must coincide with or be parallel to the edge *CD*, and the centre of the semicircle must be placed in position equidistant from the points *A* and *B*. The next step is to drive into the wood at the centre of the semicircle a fine nail or piece of wire to which a length of thin wire or silk thread is attached by a loop. Obtain a small disc of lead. Insert and fix a needle in the lead, and suspend the lead and needle from the end of the thread. Your clinometer is now complete. Before it is used, its accuracy should be tested by placing it again on a level surface. If the needle registers 0° on the graduated scale, the instrument is correctly made.

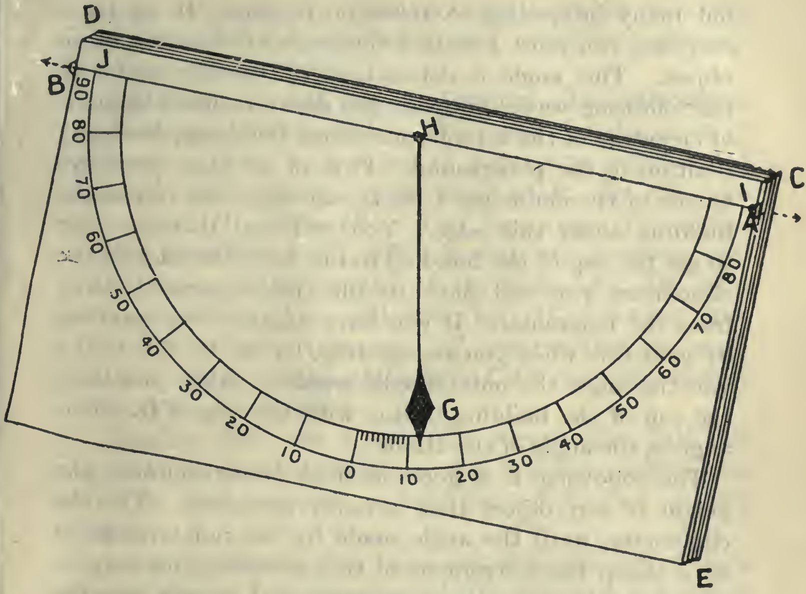

FIG. 140.

You may now perform the following exercise with the clinometer in order to understand the principle underlying its use. Tilt the edge *FE* slightly upwards from the level surface of the table, and place a protractor flat against one of its faces, and at the same time resting on the table. Read off the angle of tilt of the edge *FE* by means of the protractor. Suppose that the angle is 30°. If you look at the index needle of the clinometer you will find that it also registers 30°. The angle of tilt, or in other words the angle of inclination of the edge of the clinometer from the horizontal table, is shown by the angle that the needle marks on the semicircle.

You may now with your home-made instrument work out many interesting exercises on heights. In all these exercises you must first find the angle of elevation of an object. This angle is determined by the clinometer in the following way: Suppose you desire to find the angle of elevation of the top of your school buildings, from any position in the playground. First of all place your eye at one of the end-edges *C* or *D*, and sight the top of the building along this edge. You will find that in order to get the top of the building in line with the edge of the clinometer you will have to tilt the instrument away from the horizontal. If you have another boy standing by your side when you are sighting, he will be able to tell you the angle the index-needle registers, when you have the top of the building in line with the edge *CD*. This angle is the angle of elevation.

The following is a good method of determining the height of any object that is easily accessible. Tilt the clinometer, until the angle made by the index-needle is 45°. Keep the instrument in that position with respect to your eye, and move backwards or forwards towards the object, until you get the top of it in line with the edge *CD* of the instrument. Mark on the ground the actual spot where you find this to be the case. Measure the distance you are now away from the object. This distance is equal to the height of the building above the level of your eye. To obtain the total height of the building the height of your eye above the ground should be added to the distance measured.

The height of an object quite near you may be also found by measuring out a base-line in the direction of the object, finding the angles of elevation of the object at the ends of this base-line, and drawing a figure to scale, in the same way as that explained in the case of the theodolite (see p. 545). The same degree of accuracy cannot, however, be obtained because of the difficulty in maintaining the clinometer in a perfectly stationary position when sighting.

The Clinometer and Contour Drawing.—The clinometer is, however, chiefly used to determine the direction of contours. Draw on a sheet of paper any right-angled triangle *ABC* having a right angle at *B*. In *AB* take any point *D*. Join *DC*. You have now two right-angled triangles, *ABC*, *DBC*, having one common side *BC*. Measure the lengths of the sides *AC*, *DC*, and compare them. You will find that *AC* is longer than *DC*. At the same time you will observe that the angle *CDB* is greater than the angle *CAB* if you measure them with a protractor.

Imagine that the irregularly curved line *ABCDE* (fig. 141) represents the slope of a hill along which you wish to find contours at intervals of 10 feet *vertical height*.

From the exercise you have just done, you know that, if you started from the top, *A*, the distance you would have to go down the slope to a point *B*, 10 feet vertically below *A*, depends on the size of the angle *ABG*. If the angle is small, the slope *AB* will be gentle ; if large, the slope will be an abrupt one, and you will need to go down a shorter distance to have a vertical fall of 10 feet than would be the case if the slope were more gentle.

When the observer is standing at *A*, the direction of the horizon at *A* will be represented by a line *AH* drawn parallel to the base of the hill *EF*. *EF* is parallel to the base *BG* of the triangle *ABG*, and the line *AB* representing the slope of the hill intersects the parallels *HA* and *BG*. Therefore the alternate angles *HAB* and *ABG* are equal. Now, if when standing at *A* you were to sight, by means of the clinometer, an object at *B* of the same height as

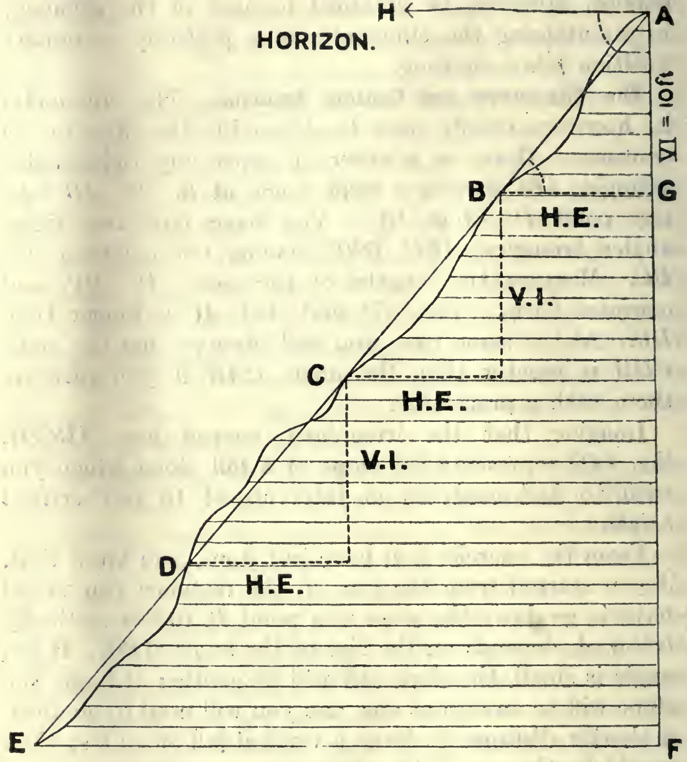

Fig. 141.

that of your eye above the ground, you would require to lower the instrument instead of tilting it, as you did when finding the angle of elevation of an object. This is because you are now finding an angle of depression. The value of this angle will be equal to the angle through which you have lowered the clinometer from the horizontal—that is, the angle *HAB* or the angle *ABG*.

You may now compile a table which will give you the distance you will have to proceed down the slope *AB* to obtain a vertical fall of 10 feet.

Choose a scale of say $\frac{1}{10}$ inch to 1 foot and draw a vertical straight line *A′E′* 1 inch long, to represent a vertical fall of 10 feet. Suppose at *A′* (fig. 142) you found the angle of depression by the clinometer to be 15°, then the angle $B'A'E' = 90° - 15° = 75°$. At *A′* make the angle $B'A'E' = 75°$, and draw *E′B′* at right angles to *A′E′*. *A′B′* represents the distance you will have to proceed down the slope to get a fall of 10 feet. Measure *A′B′*. You will find it is nearly 3·9 inches long, that is, it represents, according to the scale, a distance of 39 feet. Following this method, you may determine the distance you should go down a slope to have a vertical fall of 10 feet for any angle. In a triangle like that which you have drawn, the horizontal distance *B′E′* is termed the *horizontal equivalent*, and for small angles the difference between it and the length of *A′B′*—the *distance of slope*—is very small. We append here a table that gives the difference for all angles ranging from 1° to 15°.

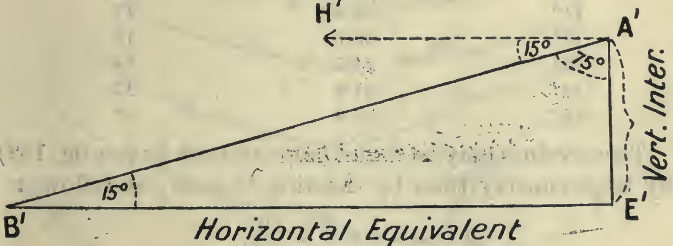

FIG. 142.

DISTANCE ALONG SLOPE AND HORIZONTAL EQUIVALENT AT VERTICAL INTERVALS OF 10 FEET

Angle of Slope. *Degrees.*	*Distance of Slope.* *Feet.*	*Horizontal Equivalent.* *Yards.*
1°	573	191
2°	286·5	95
3°	191	63
4°	143·3	47
5°	114·7	38
6°	95·7	31
7°	82	27
8°	71·9	23
9°	63·9	21
10°	57·6	19
11°	52·4	17
12°	48·1	16
13°	44·5	14
14°	41·3	13
15°	38·6	12

These values may be found more accurately (see fig. **142**) by trigonometry than by drawing to scale, as follows:

$$(a)\ \text{Cosec}\ A'B'E' = \frac{A'B'}{A'E'}$$

$$A'B' = A'E' \times \text{cosec}\ A'B'E'$$

$$\therefore\ A'B' = 10 \times \text{cosec}\ A'B'E'$$

Hence by substituting any angle for cosec $A'B'E'$ the **distance of slope** may be found.

$$(b)\ \text{Cotan}\ A'B'E' = \frac{B'E'}{A'E'}$$

$$\therefore\ B'E' = A'E' \times \text{cotan}\ A'B'E'$$

$$\therefore\ B'E' = 10 \times \text{cotan}\ A'B'E'$$

By this means the **horizontal equivalent** may be calculated.

Determination of Contour Lines by the Clinometer.—To determine the direction of contour lines by practical observation out of doors, and to trace them on a map, we should take with us three surveying poles, on which each foot is coloured black and white alternately, a tape, a compass, and the clinometer. One pole should be first set up at *S* (fig. 143). Here let one boy remain while another proceeds with the remaining poles down the slope, erecting one at some convenient distance from *S*, and the other in a direct line with it some distance farther down the hill. The object of the third pole is to secure that observations shall be made in a direct line from *S*.

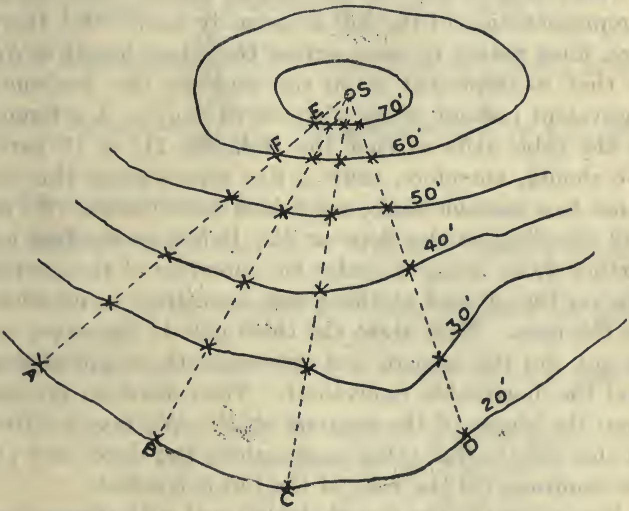

FIG. 143.

Let the boy at *S* place the clinometer so that one of its faces touches the pole at *S*, and so that the sighting-edge of the instrument coincides with any foot mark on the pole. To sight the same height * on the intermediate pole he must tilt the clinometer. The angle marked by the plumb-line should then be noted. It is equal to the angle *HAB* = *ABG* (fig. 141). Next refer to the table. Suppose the angle so found was 11°, the table tells us that we must go down the slope 52·4 feet to have a vertical fall of 10 feet. Measure off with the tape the required distance. This gives us the point *E*. The distance *SE* is measured along a slope, but on maps drawn on a plane surface we cannot represent the actual slope of the hill. This can only be done on relief models, on which would appear a representation of the hill as actually seen. We, therefore, must reduce to some extent the actual length of *SE*, so that we represent it on the map by the horizontal equivalent instead of by distance of slope. A reference to the table tells us that the *H.E.* for 11° is 17 yards. We should, therefore, draw a line representing this distance to a suitable scale, say 1 inch to 20 yards. We are still standing on the slope at *E*. Before proceeding any farther down along it, judge the direction of the contour line on the ground at this point, and draw in its course on the map. Next sight the third pole in the same way as you did the second, and determine the angle of slope and the horizontal equivalent. Then draw in on your map the shape of the contour at *F*. We may continue in this way to find other points along the slope, and plot the contours till the base of the hill is reached.

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* In practice it is well to pin a piece of paper on the intermediate pole to act as a guide in sighting.

Now return to the top of the hill and with the compass determine the direction of three or four other lines drawn along the slope. Proceed to find the contours along each of these lines and plot their positions on the map. When this is done, a complete contoured map of the hill may be obtained by connecting up all parts of each contour so determined. The height of each contour line can then be written in, taking as the datum line the last contour, or finding its height above sea-level from an Ordnance map of the district.

Contour lines may thus be drawn for any number of vertical feet interval, but a new table must be compiled similar to that given.

Determination of Gradients.*—If a table of horizontal equivalents be studied, it will be seen that, with a slope of 1°, the ratio $\frac{\text{vertical interval}}{\text{horizontal equivalent}}$ is $\frac{\text{1 foot}}{\text{19·1 yards}}$ = a gradient of $\frac{1}{57}$ or 1 in 57;

for 2° the ratio is $\frac{\text{1 foot}}{9\frac{1}{2}\text{ yds.}}$ = a gradient of $\frac{1}{28\frac{1}{2}}$ or 1 in 28½;

for 3° the ratio is $\frac{\text{1 foot}}{6\frac{1}{3}\text{ yds.}}$ = a gradient of $\frac{1}{19}$ or 1 in 19.

These results may be compared as follows:

With a vertical interval of 1 foot, 1° gives a gradient of 1 in 57.

With a vertical interval of 1 foot, 2° gives a gradient of 1 in 28½.

With a vertical interval of 1 foot, 3° gives a gradient of 1 in 19.

These gradients may be written approximately:

For 1° the gradient is 1 in 60
,, 2° ,, ,, ,, 1 ,, 30
,, 3° ,, ,, ,, 1 ,, 20.

Hence for a vertical interval of 1 foot, divide the number of degrees of slope into 60 and the gradient will be thus obtained—that is to say, 5° of slope = gradient of 1 in 12.

∴ To find the horizontal equivalent, when the slope and vertical interval are known:

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* For a more detailed treatment of Contours, see "Contours and Maps," published by Messrs. Meiklejohn & Son, Ltd., 11 Paternoster Square, London, E.C.

Divide the number of degrees of the slope into 60, multiply the result by the vertical interval in feet, and the result will give the horizontal equivalent in feet. This must be divided by 3, since the horizontal equivalent is always expressed in yards.

Or shortly:

$$H.E.\text{ in feet} = \frac{60}{\text{slope in degrees}} \times \text{vert. int.}$$

$$\text{or } H.E.\text{ in yards} = \frac{20}{\text{slope}} \times \text{vert. int.}$$

EXERCISES

1. Two places are connected by a road; the distance is a mile and a quarter, and their heights above sea-level are 106 and 206 feet respectively. What is the average gradient between them? (Camb. Jun. Loc.)
2. If you were given a contoured map on which the summits of two hills are marked *A* and *B*, and were asked *to draw a section* along the straight line joining *AB*, how would you set about it? What is the use of a section of this kind? (Oxf. Sen. Loc.)
3. A hill, 1,000 feet high, slopes gradually into the sea, at an angle of about 30° on its N.E. and S.E. sides. To the N.N.W. it is connected, by a ridge 500 feet high at its lowest point, with a conical peak 800 feet in height. To the W. it descends precipitously from the summit to a height of 600 feet; thence it falls with a more gradual slope of about 45° to a river, which runs S.E. under a smaller peak, due S. under the larger hill, and winds again to the S.E. round the base of the latter, to enter the sea. Express these relations by a map with contour lines at intervals of 200 feet vertical height. (Oxf. Sen. Loc.)

[This question differs from the ordinary type in that angles of slope are given. The slope to the

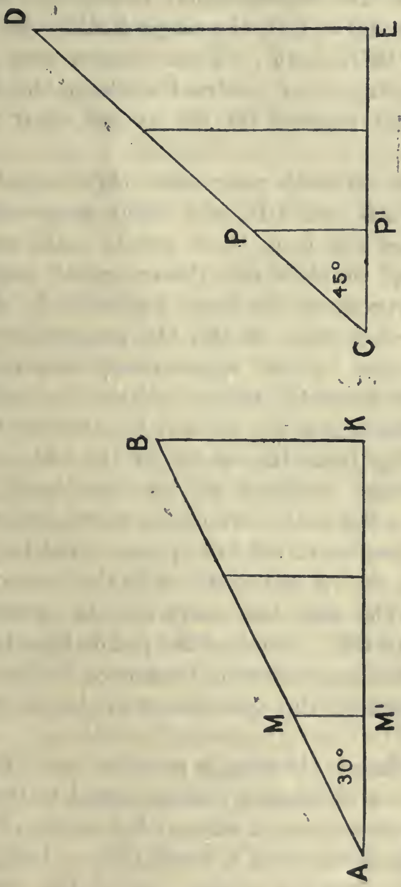

Fig. 144.

north-west and the south-east is about 30°, and the slope for some distance to the west is about

45°. The former slope is, therefore, somewhat more gentle than the latter.

Draw two right-angled triangles ABK, CDE, having $AB = CD$, the angle $BAK = 30°$, and the angle $DCE = 45°$. These angles may be made by placing your protractor along the lines AK, CE, and reading off by its aid their respective values.

Mark off with your ruler three equal divisions along AB and CD, and drop perpendiculars on AK and CE from these points AK and CE are thereby divided into three equal parts. Since AM represents the slope for an angle of 30°, and CP for an angle of 45°, the proportion * AM' to CP' gives us the approximate closeness of the contour lines to indicate what is required. This proportion may be applied by drawing three lines radiating from the centre of the hill—one to the north-east, another to the south-east, and the third to the west. Along the north-east and south-east lines mark off five spaces equal to AM', and having drawn the contours to the level of 600 feet across the west line mark off one or more spaces equal to CP'. Each of the points thus found gives you the approximate closeness of the contours. The rest of the question may be easily worked out.]

4. Draw a sketch showing a piece of main road which crosses a meadow (road unfenced on both sides), then passes over a stream by means of a bridge, next goes through a wood (where both sides are fenced), and on coming out of the wood passes

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* That is, the proportion of one horizontal distance to the other (see p. 577).

under a railway bridge. The railway crosses the road at right angles on an embankment. N.B.—Use the conventional signs employed in the maps of the Ordnance Survey. (Oxf. Sen. Loc.)

5. What is a contour map? Explain how you would recognise on such a map (*a*) a steep slope, (*b*) a gentle slope, (*c*) a *col*. If you were given a contour map, with a sufficient number of contours marked, how could you determine whether one given point was or was not visible from another? (Oxf. Jun. Loc.)

6. A church (with a spire) stands on the top of a conical hill, the hill-top being 500 feet above sea-level. A mile to the south of the church a rapid stream flows westwards, about 200 feet below. The road from the church crosses the stream by a bridge about two miles to the south-east of the church.

   Draw a rough sketch-map representing the piece of country described, on a scale of about 2 inches to a mile. Use the signs employed on Ordnance maps, and insert contours at intervals of 50 feet. (Oxf. Jun. Loc.)

7. "Walking southwards from the village which is itself about 200 feet above the level of the sea, we ascended a grassy uniform slope for about a mile, and suddenly found ourselves on the edge of a precipice which descended sheer to the sea 600 feet below us. On our right, about a mile to the westward, was the narrow estuary of the river, and on our left an open, almost circular, bay, some three miles in diameter—a narrow beach backed by cliffs some 100 to 150 feet high."

   Draw a rough sketch from this description. Make the scale about 1 inch to the mile, and draw contours at 50-foot intervals. (Oxf. and Camb. Cert.)

[A precipice can only be represented on a contoured map by one contour line. In this case that line is a natural contour, *i.e.* sea-level, so that the contour lines crossed on walking from the village to the precipice should be drawn so as to touch but not go beyond that line.]

8. You have a sheet of the Ordnance map showing a football field, and you wish to mark the positions of the goal-posts. How would you proceed? (Oxf. and Camb. Cert.)

[The Ordinance Survey map that will give you a detailed plan of a football field is the 25-inch. To mark the positions of the goal-posts, first of all convert the actual length of the touch-lines and goal-posts into their representative lengths on the plan in accordance with the scale. Also convert the actual distance of either goal-post from the nearest corner-flag into its representative length according to the scale. Draw a rectangle representing the playing area according to the scale of measurements thus obtained, and mark off the distance each goal-post is from the nearest corner.]

9. A line of railway running east and west crosses a river, which flows from north-west to south-east. Farther to the west it enters a cutting and passes under a bridge, on which is a road running north and south. West of the bridge the railway goes into a tunnel.

Draw a rough sketch-map representing the facts described. (Oxf. and Camb. Cert.)

10. A man travels in a straight line from a town, *A*, to a village, *E*, which is N.E. of *A*. *A* is at the top

of a hill 400 feet high and his path slopes uniformly for a mile to a point, *B*, on the shore of an estuary. half a mile wide. This he crosses by a boat to *C*, and then he climbs a range of hills 1,000 feet high, the summit, *D*, of which is $1\frac{1}{2}$ miles from *C*. From here he descends 400 feet in the next half-mile, and, after crossing a river flowing westward, he ascends 200 feet in the course of $\frac{1}{4}$ mile and reaches *E*, which is at the edge of a plateau.

Draw a sketch-map of his route on a scale of 1 inch to a mile, and a section illustrating the route on a vertical scale of $\frac{1}{10}$ inch to 200 feet and the same horizontal scale.

11. *A*, *B*, *C*, *D*, and *E* are five towns. A man travels N.W. from *A* to *B* 10 miles, N.E. from *B* to *C* 15 miles, E. from *C* to *D* 12 miles, S.W. from *D* to *E* 9 miles.

    Draw a map of this route on a scale of 2 miles to 1 cm., and measure the distances as the crow flies, (*a*) from *A* to *E*, (*b*) from *A* to *C*. (Civil Service.)

12. A man cycles due N. from a village, *A*, to another village, *B*, 8 miles away; then due east $9\frac{1}{2}$ miles to a third village, *C*; and finally 6 miles S.W. to a fourth village, *D*. Draw a map on a scale of $\frac{1}{2}$ inch to a mile, showing the villages, and find in miles the distance, as the crow flies, between *A* and *D*.

13. Draw a map on a scale of $\frac{1}{2}$ inch to a mile in accordance with the following description:

    X is a town situated on the centre of a large bay on the east coast of a country. A range of high hills runs 12 miles in a N.W. direction, starting from a point *Z*, 4 miles S. of *X*. At this point

Z there is a distance of $1\frac{1}{2}$ miles between the hills and the sea. Another town, *Y*, is situated S.W. of *X* and the towns are 10 miles from one another in a direct line.

Insert the probable course of a railway line between *X* and *Y*.

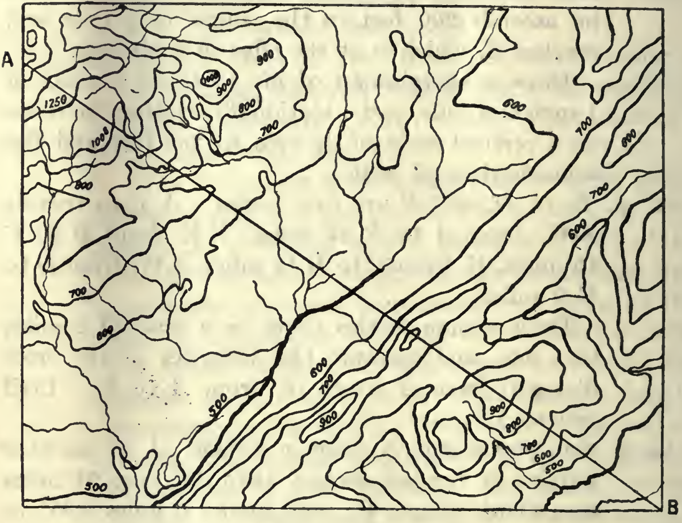

Fig. 145.

14. Describe the surface configuration and drainage of the district shown in the accompanying sketch-map (fig. 145). Draw a section along the line *AB* to show the profile of the country, using a vertical scale of 500 feet to an inch. (Central Welsh Board.)

[On reference to the map it will be seen that contours are drawn at intervals of 100 feet up to a height of 1,000 feet. After that point is reached the contours are drawn at intervals of 250 feet apart. The vertical scale suggested is 500 feet to an inch, and since the contours are drawn at intervals of 100 feet a rise or fall of 100 feet would be represented on the vertical scale by $\frac{1}{5}$ inch. You should therefore divide the vertical scale of your section into spaces of $\frac{1}{5}$ inch.]

15. A lake lies 1,000 feet above sea-level, and is surrounded by highlands rising steeply from its shores to a height of 1,300 feet above sea-level, but sloping gradually on all sides down to the sea 50 miles off.

    Draw a sketch-map, and show this by means of contour lines. (College of Preceptors.)

16. What is a contour line ? What are contour lines used for ? Can you learn anything as to gradients from them ? Give examples. (London County Council.)

17. Describe the area represented on p. 586. The figures give, in feet, the vertical distance above or below sea-level. The contour lines below sea-level are dotted. Draw a section along the diagonal *AB* representing 100 feet vertically by a $\frac{1}{4}$ inch. If the diagonal *AB* represents a distance of 34 miles, find (*a*) the scale of the map, (*b*) the area of the map in square miles. (Civil Service.)

18. Draw a contoured map of a ridge 2 miles long and $\frac{1}{2}$ mile broad, running east and west. The top of the hill is a plateau 400 feet high, 1 mile long, and $\frac{1}{8}$ mile across, and the descent is steeper on the south side than the north side. Draw the map to a scale of 4 miles to the inch, and show contour lines for every 100 feet. (Civil Service.)

19. Draw a contoured map of an imaginary island. In the centre of the island is a pass 2,000 feet high

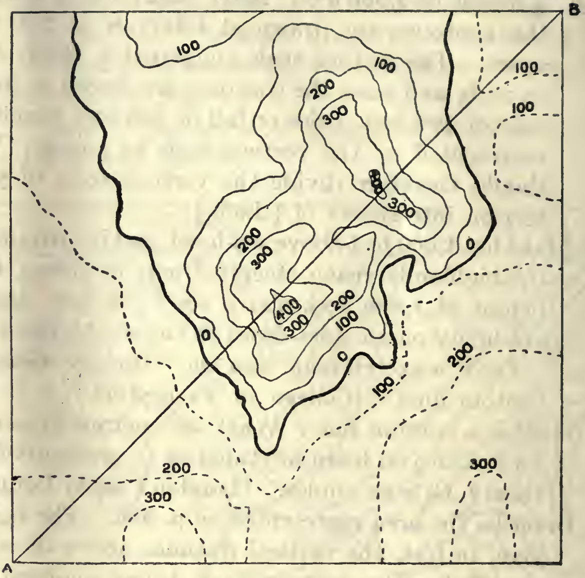

FIG. 146.

crossing a mountain-ridge that runs due east and west. The slope upwards from the pass on the east is a gradual one, attaining an elevation of 4,500 feet, from which point the land descends precipitously towards the sea. To the west of the pass the ascent is steep, till it reaches a height of 5,000 feet, from which a gradual descent takes place to the sea. There are two rivers flowing from near the summit of the pass—one due north, the other south-east.

Insert contour lines at intervals of 500 feet.

CHAPTER XXXVII

The Making of Maps

In mapping small areas of the earth's surface, the earth's sphericity is not taken into consideration; but when maps are drawn on which a comparatively large area like that of England is represented, an accurate representation cannot be obtained unless the spherical form of the earth be taken into account. As the earth's shape closely approaches that of a sphere, the only means by which an accurate map of its surface can be secured is by representing it on a sphere or globe. But such a globe would need to be of enormous dimensions, if it were to show the detail of every separate region, so that it has been necessary to devise other methods which will give, on a flat or plane surface, as fair a representation as possible. The methods by which parts of the earth's surface are mapped on a plane surface are called **projections**; but not one of them entirely overcomes the difficulty, because it is clearly apparent that a spherical surface cannot be placed on a plane surface without suffering some distortion.

Meaning of Projection.—The word Projection means a "throwing forward," and the term as it is used in the cartographical sense implies that the shape of some object is thrown forward by a lighted body. For example, the shadow of a tree cast on the ground by the sun might be considered as a projection of the tree. Better still, hold a rubber ball before a lamp in a semi-darkened room and at the same time keep it close to one of the walls. A shadow of the ball is cast on the wall and is said to be projected by the light from the lamp. If the ball be moved farther away from the wall, the shadow will be observed to grow larger and larger as the ball recedes from the wall until a point is reached when it extends over the whole wall. One more illustration: When a picture slide is placed in a lantern, the light within the lantern projects the picture on the screen. In this case the size of the picture shown on the screen depends upon the positions of the lenses of the lantern, and by changing their positions the picture may be increased or diminished in size at will. Imagine that the picture is made up of a set of points. A clear impression of the meaning of projection is gained by considering a set of lines to be drawn from the flame within the lantern to all points on the slide and then produced to reach the screen. The relative positions of all points on the slide are thereby correctly reproduced on the screen, and are projected by straight lines drawn from the lantern flame. In the reproduction the picture coincides in every respect with that on the slide except in so far as it is magnified. Now consider what would happen if, instead of the slide, a hollow semi-globe of glass (fig. 147) on which the parallels and meridians were marked in black on its convex surface, were held immediately before the lantern. The equator and the central meridian would be projected to the screen as straight lines, not as semicircles which they actually are. The other semicircles would be projected as slightly curved lines, but more nearly straight according as they were nearer to the equator or to the central meridian.

Different Forms of Projection.—Many different forms of projection have been devised, the best known being —Stereographic, Orthographic, Globular, Cylindrical, Mercator's, and Conical. In each of these there are distortions of one kind or another. The two chief features represented on every map are: (i) direction, (ii) distance. Either the one or the other of these is affected according to the projection on which the map is drawn. For example, in stereographic projection distance is not quite accurate, and direction is very inaccurate; in Mercator's (partially cylindrical) distance is quite inaccurate, the equator being the only line accurately represented, whereas direction is absolutely accurate; in globular or equal-area projection distance is accurate while direction is inaccurate, and so on. These features may be shown by using the lantern and the transparent hollow semi-globe previously mentioned. Along the central meridian on the convex surface (fig. 147) mark any number of equal intervals, 1, 2, 3, 4, 5, etc. Place the semi-globe so that the lantern is at *L*. The meridian *XY* will be projected on the screen as a vertical straight line, but the intervals along the projected line, if measured, will be found to be unequal; they increase from the middle interval outwards. If the sphere be now shifted slightly forward from the lantern, or the light moved back to L_1, the inequality in the lengths

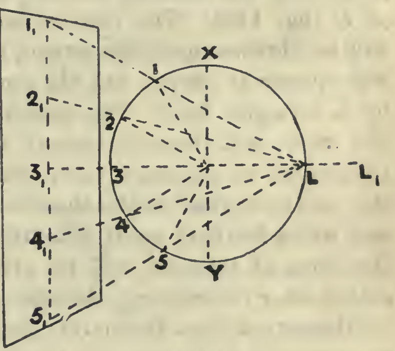

Fig. 147.

of the intervals will be observed to decrease somewhat, until a point is reached at which the distortion is at a minimum. If the light be placed at the centre of the semi-globe, the inequality in the lengths of the projected intervals would be more pronounced, as may be seen by producing the dotted lines from the centre to the screen.

Stereographic Projection.—To illustrate this form of projection the lantern should be placed with the light at *L* (fig. 148). The convex surface of the semi-globe will be thrown upon the screen, and the lines of latitude will appear as curves, but the equator will be represented by a straight line. The meridians, except the central one at *O*, will likewise appear as curved lines, but will be noticed to approach each other more closely towards the centre of the circle that represents the semi-globe, and to be farthest apart near the edge. In like manner the lines of latitude will be observed to be closest together near the centre. Because of this the angles formed by the actual lines drawn on the globe are badly distorted in projection. Hence countries situated near the centre of a map drawn on this projection suffer compression, while those near the outside rim are enlarged. The distortion in either case is, however, not extreme.

The following is a practical exercise on this type of projection: Draw a circle *AOBL* (fig. 148) of suitable radius, say 1½ inches, to represent a sphere on which the earth's surface is mapped. Insert two diameters *OL*, *AB*, at right angles to each other and intersecting at *P*. Suppose that the surface of the globe be projected so that *P* represents a pole of the earth, then the circumference of the circle represents the equator. Divide the semicircle *AOB* into six equal parts, each arc containing 30° longitude. Imagine the light to be placed at *L*, and that a screen

A^1OB^1 touches the globe as a tangent at O; then each of the points R, S, O, T, and U may be projected on the screen by producing the lines connecting these points with L. With centre O and radius OA^1 describe a semicircle $A^1P^1B^1$. If the lines LR, LS, LO, LT, and LU be produced until they cut the semicircle, the points R^1, S^1, P^1, T^1, and U^1 thus obtained will be the positions of R, S, P, T, and U projected. Join S^1T^1, R^1U^1 by curved lines and likewise connect P^1 by curved lines with each of the points previously obtained on the screen. On the projected semicircle P^1 represents the pole, S^1T^1, R^1U^1 lines of latitude, and all lines radiating from P^1 are meridians.

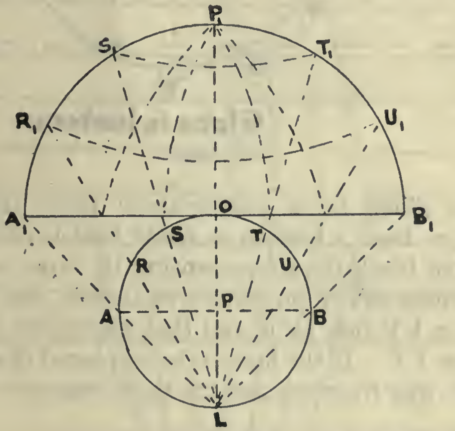

FIG. 148.

Orthographic Projection.—In this method of projection, since the light must come from an infinite distance (in order that the rays may be parallel) compared with the distance between the hollow semi-globe and the screen, the light of the sun can be used to project the lines

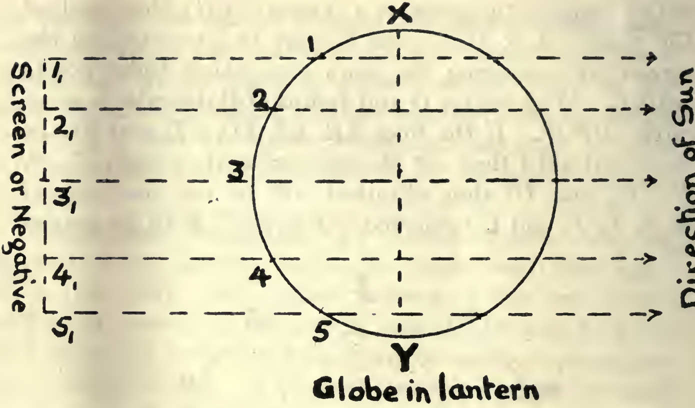

FIG. 149A.

from the globe to a photographic plate (fig. 149A). Suppose we have a lantern so made that a hollow semi-globe, with black lines representing the lines of latitude and meridians drawn on its convex surface, can be placed in position *YY* (fig. 149B) and that a negative is inserted in the slot *XX*. If the lantern be so placed that the lens is turned away from the sun, the light from the sun would

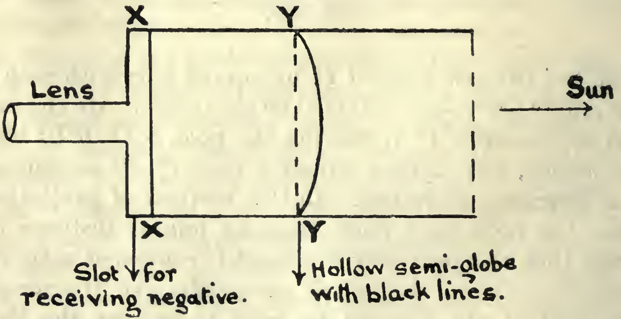
X
Y
Lens
Sun
X
Y
Slot for receiving negative.
Hollow semi-globe with black lines.

FIG. 149B.

project the black lines of the globe upon the negative at *XX*. In this case the light would come from an infinite distance, and all lines drawn from the globe to the negative might be considered as parallel (fig. 149B). This system is called orthographic projection. It is obvious that the parallels of latitude will be projected as straight lines

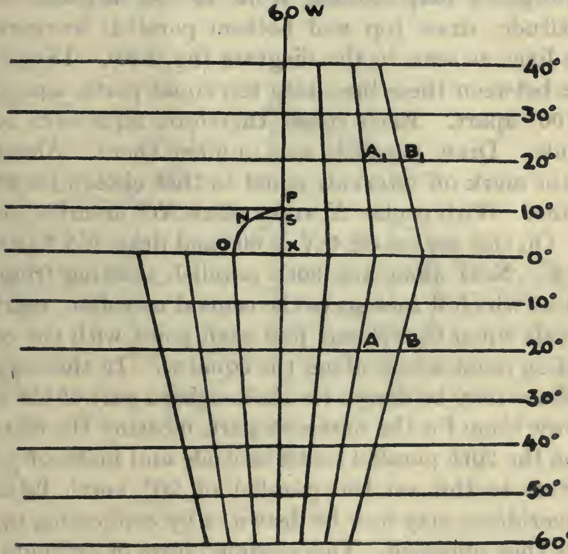

Fig. 150.

but the meridians will be represented as curves. The effect of this is that areas near the outside are diminished, because the meridians approach each other more closely from the centre of the circle projected outwards. Places situated near the centre of the circle will show only slight distortion, so slight that they may be considered as being represented fairly accurately. Maps of the polar regions are frequently drawn on this projection.

A modification of this projection can be drawn in the following way. Suppose we wish to draw South America on orthographic projection. First draw the central meridian. For South America this is 60° W. Then since the proposed map extends from 40° N. latitude to 60° S. latitude, draw top and bottom parallels to represent these lines as seen in the diagram (fig. 150). Divide the space between these lines into ten equal parts, since they are 100° apart. Each space, therefore, represents 10° of latitude. Draw parallels and number them. Along the equator mark off intervals equal to that chosen for 10° of latitude. With centre X and radius XO describe an arc OP. On this arc set off $ON = 60°$ and draw NS * parallel to OX. Next along the 60th parallel, starting from the point at which it intersects the central meridian, mark off intervals equal to NS and join each point with the corresponding point set off along the equator. In this way the meridians may be drawn for the southern part of the map. To draw them for the northern part, measure the distance AB on the 20th parallel south latitude and mark off equal intervals to this on the parallel of 20° north latitude. The meridians may now be drawn in by connecting up the points thus obtained. This modified form of orthographic projection is good only for continents.

Globular or Equidistant Projection.—It has been shown that both the stereographic and orthographic systems result in distortion—one distorts the central portion of the map, the other the edges or margin. Hence it was supposed that if the light were placed at some point intermediate between those chosen for these projections, there would be found a mean position that would reduce the distortions in each case. For this purpose globular projection was devised. In this method the semi-globe is placed outside the lantern and the extreme end of the lens is fixed in position at *L* (fig. 151), so that the distance *LT* is half the chord *ST* of the quadrant *TOS*. It will be observed that the intervals along the line *XY* on the screen are approximately equal, and that all lines on the globe are projected upon the screen in the same way as that described for stereographic projection. The exact position of the lantern in globular projection is determined by remembering that $LT = \frac{ST}{2}$

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* If NS were required to be marked on the 50th parallel, the arc ON would be 50°, and so on.

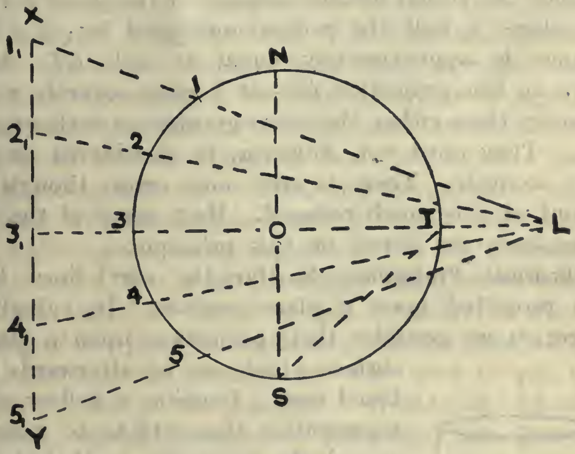

FIG. 151.

The distance of the point *L* from the sphere in terms of the radius is found as follows:

$$ST^2 = OS^2 + OT^2$$
$$\therefore ST = \sqrt{OS^2 + OT^2}$$
$$\therefore ST = \sqrt{2r^2}$$
$$\therefore ST = r\sqrt{2}$$
$$\text{Since } LT = \tfrac{1}{2}ST$$
$$\therefore LT = \frac{r}{2}\sqrt{2} = \frac{r}{\sqrt{2}}$$

Hence the actual distance chosen of the point L from the sphere is half the radius multiplied by $\sqrt{2}$. This distance is approximately equal to half ST. Maps drawn on this projection present a more accurate representation than either the stereographic or orthographic form. They must not, however, be considered as perfectly accurate. There is still some error, though the amount of it is much reduced. Most maps of the two hemispheres are drawn on this principle.

Cylindrical Projection.—So far the earth-lines have been projected upon a plane surface. In cylindrical projection we consider their projection upon a curved surface which can be afterwards flattened out. Imagine a hollow globe representing the earth to be enclosed in a hollow cylinder, so that it just touches the cylinder along the circumference of a great circle AB (fig. 152), and that a light is placed in the centre L of the globe. The rays of light will project the parallels as circles round the inner surface of the cylinder until the cylinder is unrolled, and when this is done they will appear as parallel straight lines. The meridians will be projected as vertical straight lines.

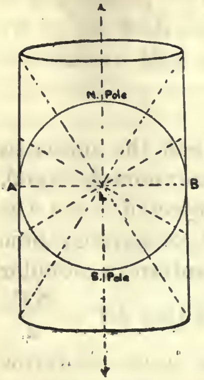

FIG. 152.

It is clear from the diagram that a limit will be reached above and below the equator *AB* at which it will be impossible conveniently to project the lines of latitude and parts of the meridians. In fact, the poles cannot be projected at all, because lines connecting these points with the light at the centre of the globe would not, if produced, touch the inner surface of the cylinder. Only a portion of the earth's surface can therefore be mapped by this projection. Imagine the cylinder to be unrolled and flattened out ; the lines of latitude and meridians would appear to intersect each other at right angles. But while the distance between each pair of meridians is the same throughout, the distance between each pair of lines of latitude increases from the equator northwards and southwards. Areas, therefore, situated in high latitudes will be elongated and greatly exaggerated in size, while areas near the equator will be fairly accurately represented. The great advantage this form of projection has above all others is that it preserves the true bearing of one place to another.* For this reason it is of inestimable service to mariners who need to sail their vessels by aid of the compass. World-maps of ocean currents, winds, isobars, or isotherms, are generally drawn by this projection.

The following is a practical exercise on this type of projection: Draw a circle of suitable radius to represent the earth (fig. 153). In it place two diameters *NS*, *RP*, intersecting at right angles at its centre *O*. Draw two tangents at the points *R* and *P* respectively, to represent the curved surface of the cylinder. At *O* divide the angle *NOP* into any number of equal parts, say 30° in each part, and produce the lines thus forming the angles to meet the tangent *QT*. In like manner divide the angle *SOP* into the same number of equal parts and draw the lines to meet *QT*. Produce the diameter *RP* till the produced part *PW* is equal to the circumference of the sphere. *PW* will then represent the equator. Next draw a set of lines parallel to *PW* from all points along *QT* where that line is met by the lines radiating from the centre of the circle; each of these lines will represent a parallel of latitude. To obtain the points along *PW* where the meridians cross, divide *PW* into thirty-six equal divisions, because there are 360 degrees in a circle and this would make the interval between any pair of meridians 10°. At each of the points thus found erect a perpendicular to *PW*, and you will then have projected a network on which that portion of the earth's surface situated between the parallels 60° N. and 60° S. latitude may be mapped according to cylindrical projection.

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* If any two places on a map of this kind be connected by a straight line, such a line gives the actual direction from one place to the other, and is called a *rhumb line*. The shortest distance between the two places is the arc of the great circle passing through them. This follows because all lines on the earth's surface are arcs of circles, and the smaller a circle is the less is its circumference like a straight line.

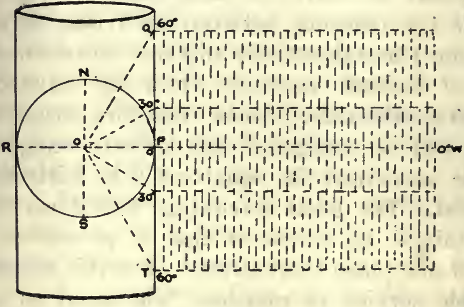

FIG. 153.

Mercator's Projection.—This system is a modified form of cylindrical projection. In cylindrical projection it has been shown that enormous distortion takes place in countries far away from the equator. For example, the impression given on such a map is that Greenland is almost as large as Africa. To reduce this distortion, the Flemish geographer named Gerhard Kremer, better known as Mercator, devised his system, which first appeared in a chart published by him in 1556. A clear idea of the distortion that occurs in cylindrical projection may be gained by taking the peel of half an orange and making cuts in it at two opposite points, as thus :

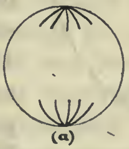

FIG. 154A.

The slits enable you to flatten the peel, when it will be seen to assume this shape :

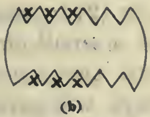

FIG. 154B.

In the flattening process the whole surface of the peel is preserved, and if the spaces *XXXX* be filled up, an exact counterpart of what occurs in cylindrical projection is thereby obtained. Mercator modified cylindrical projection by reducing the intervals between the parallels of latitude in "high" latitudes, while at the same time preserving the true shape of the land masses so affected —a similar change to that undergone by the peel of the orange. From what has been said it is obvious that neither distances nor areas should be calculated on maps of this kind, otherwise gross inaccuracies will result; but if the true bearing of one place from another is required, this is the form of projection to use.

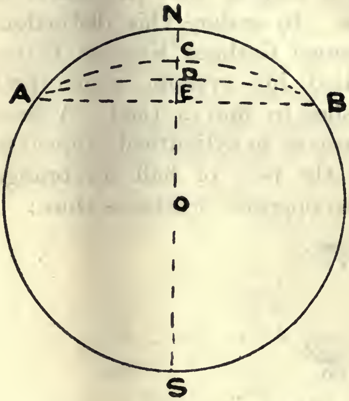

FIG. 155.

Use of Mercator's Projection. — Imagine the circle with centre *O* (fig. 155) to represent a sphere and *A* and *B* any two points on its surface. If the distance between *A* and *B* is to be measured, it may be done in two ways: (1) by measuring their distance apart along the arc of a great circle—that is, a circle that divides the sphere into two equal parts; or (2) by measuring their distance apart along the arc of a small circle—that is, one that divides the sphere into two unequal parts. Consider which of these two ways will give the shorter distance between the two points. It is obvious that the radius of a great circle is greater than that of a small circle, therefore the degree of curvature along the circumference of a great circle is less than that along the circumference of a small circle (see p. 597). If the two arcs *ADB*, *ACB*, be drawn on the sphere to represent the difference in curvature of a great and small circle respectively, then the distance between *A* and *B* as measured along the arc *ADB* will be clearly less than that measured along the arc *ACB*, because the arc *ADB* approaches more nearly the straight line *AEB* joining the two points. All parallels of latitude are small circles. Hence the shortest distance between any two places situated on any parallel is measured *not* along the arc of the parallel of latitude, but along the arc of the great circle passing through these places. This is true in respect of all places on our globe, except those situated *on the equator*, which is itself a great circle, so long as the distance measured is in any direction except along a north-to-south line. Of course, since all meridians are arcs of great circles, the shortest distance between two places on a north-south line will lie along the meridian passing through the two places. That the shortest distance between any two places lies along the arc of a great circle may be verified by measuring on a globe the arcs of a great and a small circle with a thread and comparing the measurements.

Suppose that a sea-captain has a chart on Mercator's projection before him, and he wants to sail his vessel from a port *X* to another *Y* (fig. 156). By drawing a line on the chart connecting these points he can determine with accuracy the bearing of *Y* from *X* on the compass. He next calculates the distance between the two ports along the great circle passing through them, so as to obtain his shortest route. During the voyage he directs the course of his vessel along this circle. Assuming that *Y* lies somewhere east of *X* as seen in the diagram, the

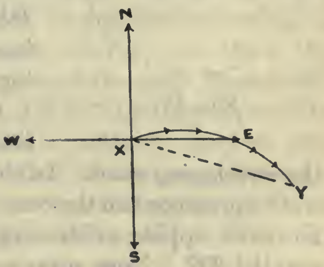

FIG. 156.

vessel's course would be first of all directed east by north; then when the maximum curvature of the arc of the great circle was reached, it would be altered to a more or less southerly direction. This method of sailing is termed **sailing by great circles,** and a considerable distance is saved at sea by navigating vessels in this manner.

Conical Projection.—For mapping small areas of the earth's surface this form of projection is the most suitable, because the error from distortion is very small indeed. Imagine that a hollow cone is so placed over a transparent sphere that it touches the central parallel of latitude of the area required to be mapped, and that a light is placed at the centre of the sphere (fig. 157). If the inside surface of the cone touches the sphere along the parallel *DE*, the parallels *FG* and *BC*, which are equi-distant from *DE*, may be projected upon the inner surface of the cone by drawing a series of lines from the light *L* to them and producing these lines until they meet the surface of the enveloping cone. In this way the parallels of latitude will be projected on the cone as circles. The meridians will, however, appear as straight lines converging towards the parallel *FG*. Now suppose the cone to be slit along a straight line from *B* to the apex *A*, and then flattened out. A network similar to that seen in fig. 158 would thus be obtained. The district mapped has for its centre the arc *DE* and the limit of the map is marked on the north by the arc *FG*; on the south by the arc *BC*. The distortion is very small and depends on the area mapped; the

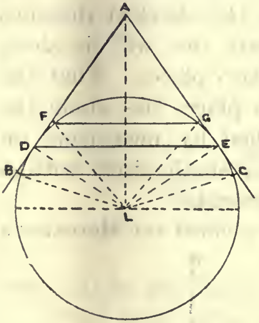

Fig. 157.

larger the area, the greater the distortion; the smaller the area, the less the distortion. The great feature of conical projection is that there is no distortion at the edges of the map. If you refer to your atlas you will notice that a large number of maps (especially those of single countries) are drawn on this method. Maps of Europe and lesser areas, on which the distance between the extreme parallels does not exceed 40° of latitude, are fairly accurately represented.

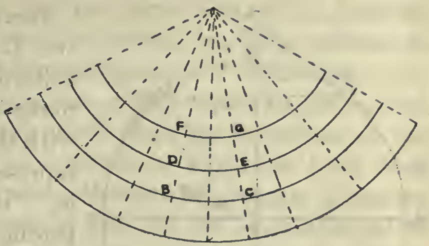

Fig. 158.

This system, like the cylindrical, has undergone some modification to reduce the degree of distortion. Instead of imagining the cone to touch the intermediate parallel of the area mapped, it is made to cut the sphere along two parallels distant from each other by one-third the total length of the map from north to south. If NT (fig. 159) represents the distance between the two outside parallels of the map, the cone is made to cut the sphere at S and P, so that $ST = SP = PN$. In this way the error of distortion is more evenly distributed over the whole area of the map.

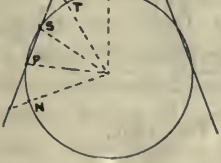

Fig. 159.

Let us put this principle into practice by drawing a map of England on conical projection. The mid-latitude of England is 53° N. (approximately),

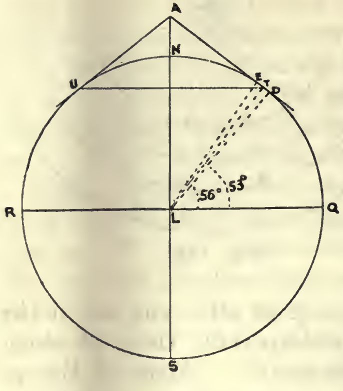

FIG. 160A.

Draw a circle with centre *L* (fig. 160A) and of suitable radius.* At *L* make an angle *QLT* of 53° with the diameter *RQ* which represents the equator. *T* is, therefore, a point through which the parallel of 53° N. latitude passes. Draw another diameter *NS* at right angles to *RQ* and let fall a perpendicular to it from *T*, and produce the perpendicular to meet the circle again at *U*. Next draw tangents at *U* and *T* respectively to meet at *A*. Since England is situated between the parallels 50° N. and 56° N. latitude, make the angles *DLQ* and *ELQ* equal to 50° and 56° respectively. Now measure *AD*, *AT*, and *AE*, and describe arcs of concentric circles, each arc having for its radius one of these lines (fig. 160B). Draw a straight line A^1D^1 from their common centre to meet the outside arc at D^1. This line will represent a meridian, and the arcs the parallels of latitude 50° N., 53° N., and 56° N. The total length of 53° N. latitude is the circumference of the circle traced on the globe passing through *U* and *T* (fig. 160A), and the radius of that circle is half the

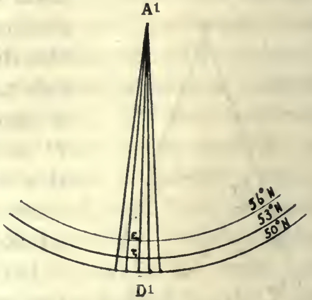

FIG. 160B.

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* A suitable radius will be found to be anything over 3 inches.

line *UT*. It is clear that the parallel of 53° N. latitude as seen in fig. 160B must be divided by the meridians in the same way as the circumference *UT* (fig. 160A). To do this describe a circle with radius equal to *AT* and at its centre make an angle of 3°, since the meridians on the map must be drawn at intervals of 3°, as has been done with the lines of latitude. Measure the length of the arc of the circle thus obtained and cut off lengths equal to this arc along the parallel 53° N. latitude (fig. 160B). Join each of the points so determined with A^1. In this way a conical projection may be drawn suitable for the representation of a map of England.

Equal-area Projections.—In nearly all projections so far described the object has been to obtain a representation of exact similarity to that portion of the sphere mapped. This has been done at the expense of sacrificing equality of areas ; the area of the portion mapped being in every case either more or less than the corresponding portion of the sphere. No projection can give us both, that is, preserve exact similarity, and at the same time secure that areas are shown in the true relation that they should bear to the corresponding areas on the globe But if the idea of similarity is given up, we may at its expense retain equality of areas. This is what is done in so-called *equal-area projections*. Of these there are several forms, of which the best known are the cylindrical equal-area (see fig. 161), the modified conical equal-area (see fig. 159), and Mollweide's or the elliptical equal-area projections (see fig. 162). All of these, although invaluable for the purpose of exhibiting and comparing areas of various states and countries—as, for example, comparing the relative proportion which the area of Tasmania bears to Great Britain—are, nevertheless, valueless if the true shape of different countries is desired. Maps on these projections, as well as those on the Mercator projection, are often used as wind and current charts, since they give us a correct representation of the true magnitude of these movements.

Equal-area Cylindrical Projection.—As in the construction of a map on the principle of the simple cylindrical projection (see fig. 152), a hollow cylinder is supposed to envelop the globe, so that the cylinder touches the equator. The parallels of latitude and meridians are now projected on the surface of the cylinder by a set of parallel straight lines drawn from infinity, and not as in simple cylindrical projection by straight lines drawn from the centre of the sphere. When the cylinder is unrolled the whole surface of the sphere will be represented as a rectangle (fig. 161), and as before the meridians will be shown as parallel straight lines at equal distances apart. The parallels of latitude will also be projected as parallel straight lines, each one being of equal length to the equator, as is the case in orthographic projection. The result of this projection is that any belt on the sphere is equal in area to the corresponding portion which represents it on the map.

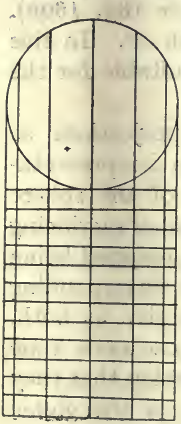
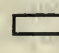


FIG. 161.

By this we mean that if we were to choose a section of the surface of the sphere bounded by meridians and parallels, it would be represented by a rectangle  which is of exactly the same area. In other words, the scale for areas is the same all over the map, and this is due to the fact that the scale from north to south decreases in the same proportion as the scale from east to west increases. Although the areas on this projection are preserved, the shapes are, especially away from the equator, much distorted.

Mollweide's Equal-area Projection.—Mollweide's (fig. 162) is sometimes called homalographic * projection. In this projection the whole earth may be mapped on an ellipse whose area is equivalent to that of the sphere. For this reason it is sometimes styled the elliptical equal-area projection. The parallels of latitude are represented as parallel straight lines and the meridians are shown as ellipses, the zero meridian being drawn as a straight line at right angles to the equator. The major axis of the ellipse, which represents the equator, is drawn twice the length of the minor axis, which is the zero meridian. The equator is equally divided. For example, if it is desired to show the meridians at intervals of 10°, then the equator will need to be marked off into thirty-six equal distances, and the zero meridian will be divided into eighteen equal divisions to mark the points through which the parallels of latitude will be drawn. In this

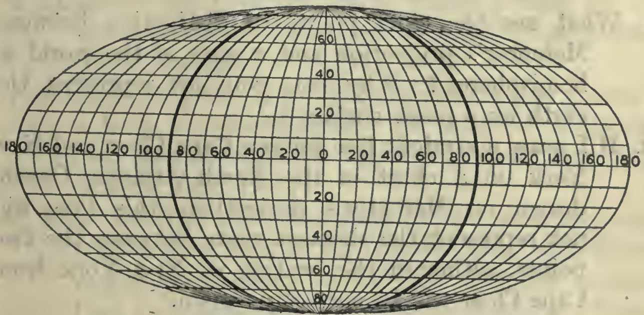


FIG. 162.

* Greek *homalos*, even.

way a map on Mollweide's projection may be obtained. It will be remarked that each elliptical meridian has for one axis the central meridian, and for the other the intercepted portion of the equally divided equator; also that the 90th meridians east and west of the zero meridian form a circle.

EXERCISES

1. What are the chief points of distinction between Mercator's projection and a map of the world in hemispheres? Why can you not represent the earth on a plane surface?
2. If I draw a straight line joining Cape Clear and New York on a chart of the North Atlantic Ocean, drawn on Mercator's projection, this line will not represent the shortest route between the two points, although the bearing of New York from Cape Clear will be correctly shown.

   Explain this. How would the shortest route be represented on the Mercator chart? Can you name any chart on which the shortest route would be a straight line? (Oxf. and Camb. Lower Cert.)
3. A map of North America has the latitudes marked by arcs of concentric circles, and the longitudes are marked by curved lines, except in the case of the central one, which is straight. Explain the principles on which such a map is drawn, and show to what extent the scale of miles provided with it may be used for measuring distances.
4. Give the construction of a network of latitudes and longitudes which will show areas truly. What are the advantages and disadvantages of a map

on such a network? And for what purposes should you select it? (Lond. Matric.)

5. What is the difference between a "great circle" and a "small circle" on the globe? Explain why the shortest distance between two places on the same meridian is along that meridian, but the shortest distance between two places on the same parallel of latitude is not, in general, along that parallel. (Oxf. Jun. Loc.)
6. Describe the principle upon which a map of the world is constructed on Mercator's projection. (Civil Service.)
7. Explain why the scale of units attached to a map of a large continent cannot be used for measuring long distances in all directions upon that map. (Camb. Jun. Loc.)
8. State exactly what is meant by the term map-projection, and explain (*a*) how the chief difficulty of map-making arises, and (*b*) the different qualities that are possessed by different projections. (Lond. Matric.)
9. Draw parallels of latitude and meridians for a map of the eastern hemisphere on the stereographic projection, the plane of projection passing through the meridian of Greenwich. Only the following parallels and meridians need be shown: the equator, and parallels of latitude for 45° N. and 45° S.; meridians for 45° E., 90° E., and 135° E. (Civil Service.)
10. Explain how to draw meridians and parallels of latitude for a map of the hemisphere on the orthographic projection. (Civil Service.)
11. If you were given a map of a small area drawn on Mercator's projection, how would you find the

distance between two points on it? Can a map of the polar regions be constructed on the same principle? Give your reasons.

12. Explain the conical projection for making maps and point out its advantages and disadvantages. (Camb. Sen. Loc.)
13. What are the special advantages and disadvantages of a map on an "equal-area" projection? Mention any purposes for which you would prefer to use such a map. (Oxf. Sen. Loc.)
14. What are the principles on which maps on orthographic and stereographic projections are drawn? By what means has the error of distortion in each case been much reduced?
15. Explain as fully as you can the method by which a map of the world is drawn (*a*) on Mercator's projection, (*b*) on any other projection with the equator running through the middle of the map. (Oxf. and Camb. Sch. Cert.)
16. Discuss any method you know of for representing a considerable portion of the earth's surface upon a plane, explaining the difficulty which has to be overcome, and pointing out the defects of the method which you select. (Oxf. Sen. Loc.)
17. Describe a mode of constructing an equal-area network for a map of a large part of the earth's surface. Discuss the nature and extent of the angular distortion in different parts of the map. (Civil Service.)

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